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16. Abstract

Phosphate slimes have been produced by the Florida phosphate mining industry at the rate of millions of cubic yards per year and the volume is increasing. The water retentive characteristics of the clays which are mined with the rock are such that there is more volume of phosphate slime to dispose of than there was actual rock mined. Small scale tests of the slimes were made to assess the feasibility of their use as building materials. A process was developed and demonstrated to be capable of producing a pelletized, light-weight aggregate, and finally a light-weight concrete from the slimes. The four major processing steps: (1) pumping of clay slurries of 3 to 30% solids; (2) slime drying in a fluid bed dryer; (3) pelletizing the dried product; and (4) kilning the product to a suitable aggregate, were investigated in batch and suitable equitment was selected. Aggretage production could use up to 6-8 million tons of clay solids annually, releasing up to 5 billion gallons of water to the environment. (Lowry-Texas)

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Utilization of Phosphate Slimes

by

International Minerals & Chemical Corporation
5401 Old Orchard Road
Skokie, Illinois 60076

for the

Environmental Protection Agency

Project #14050 EPU

August 1971

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ABSTRACT

Small scale tests were made to assess the feasibility of producing materials economically for the building industry from the clay slimes wastes of the Florida phosphate industry. The objective was to find practical means to utilize these clay materials in order to reduce or eliminate the vast empoundment acreage devoted to their storage and to make the water entrapped therein available for re-use.

These studies showed that it is feasible to produce a pelletized lightweight aggregate and ultimately a lightweight concrete from the slimes. It was estimated that up to 6 - 8 million tons of clay solids can be so used annually with the concurrent release of up to 5 billion gallons of water into the environment. Production of ceramic materials was also explored.

The four major processing steps were investigated batchwise on individual equipment types, and equipment suitable for each was identified. These steps included: pumping clay-slurries of 3 - 30% solids concentration; drying of the slimes in a fluid-bed dryer; pelletizing the dried product; and kilning it to a suitable lightweight aggregate.

This report was submitted in fulfillment of grant #14050 EPU, between the Federal Water Quality Administration and International Minerals & Chemical Corporation.

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PREFACE

As this project approached conclusion, it was deemed proper by the Grantee to obtain an objective assessment of its nature, content, and potential value from an authoritative and unbiased third-party. To this end, the services of Dr. Donald F. Othmer, Consulting Chemical Engineer, were obtained. As co-editor of the Kirk-Othmer "Encyclopedia of Chemical Technology" and one of the outstanding figures in Engineering, Dr. Othmer brings to this context a vast experience and knowledge so well known to the profession that it need not be repeated here. Dr. Othmer's incisive evaluation of this program so clearly delineated present values and future needs, that it is reproduced here in its original form. (See Appendix A.)

Srini Vasan
Project Director

CONCLUSIONS

This project has shown, in semi-batch tests of individual pieces of equipment, that it is feasible to produce, for a market of substantial size, lightweight concrete with attractive properties using dried, fired pellets of phosphate slimes as aggregate.

A fluid-bed dryer has been tested which is significantly more efficient than drying systems previously proposed for these slimes. A pelletizing technique has been developed which can reliably be adapted to the new drying and kiln systems.

Lightweight concrete produced from aggregate-from-slimes showed good strength and density characteristics. It met all the ASTM specifications (ASTM C330) for Lightweight Aggregate.

Two alternate pumping systems have been developed which could dependably remove pond-slimes from present storage areas and deliver both these and slime-slurries (concentrated up to 30% solids) to the dewatering and drying facilities.

The feasibility of producing other potential products such as ceramic tile, pipe, and brick was technically confirmed (with a few technical hurdles yet to be cleared) and our evaluation showed that further development of these materials may not be warranted till the cost-gap on these materials can be closed, especially in view of their limited market in Florida.

RECOMMENDATIONS

Successful batch-scale testing has proven that phosphate-slimes can be dried efficiently and a superior aggregate with strength, attractive for consumption in the Florida building industry, has been developed in small-scale equipment. It is therefore recommended that -- an on-site continuous Demonstration Project be conducted to develop further these indicated benefits. It is recommended that:

The Demonstration Project be devoted to the following objectives:

(1) Production of aggregates-from-slimes at site using fresh slimes as a continuous feed in a dryer-agglomerator-kiln unit.

(2) Operation of this Pilot Unit at an optimum size for scaleup purposes for a future commercial plant (preferably a 5 ton per hour, or 100 tons per day Dryer-Agglomerator-Kiln pilot unit).

(3) Product-quality assessment for determining acceptability of aggregate in various lightweight concrete formulations.

(4) Field-evaluation of product in select markets.

(5) Reassessment of potential in fines of dried-slimes in pipe, bricks, and other products.

INTRODUCTION

Disposal of wastes from Florida phosphate mining operations is an enormous and continually increasing problem. The major constituents of these wastes are clay minerals, or slimes, whose retention of water increases their volume six to ten times. As a result, the volume of waste exceeds the original volume of rock removed and requires above-grade storage. This is not only costly in terms of useless land and storage dikes but also is hazardous in terms of potential spillage, pollution of streams, and damage to residential and industrial property.

Many studies have been made, both by government and industry, of various means to alleviate this problem. These have included attempts to recover water for re-use, to reclaim P_2O_5 values contained in these wastes, and to make the clays themselves useful either for industrial or land-fill purposes. None of these have so far been fruitful due to the high costs of handling the vast quantities of aqueous waste, and of energy required to separate clay and water.

For this study, it was proposed that there are two key elements in developing an economical method for disposing of these wastes and alleviating the pollution potential. First it is necessary to develop a more efficient and less costly method of obtaining dry clay from the waste stream. Second, it is necessary to develop useful products which can be made from the dewatered clay, the value of which can support the processing costs, and the volume of which is sufficient to utilize a significant portion of the wastes available.

In the course of this study, a drying system was developed which is significantly more efficient and less costly than the conventional drying methods which previous investigators have used. This drying system utilizes a fluidized-bed which has been shown to be feasible for drying the phosphate slimes at an efficient rate. The practicality of this dryer has been demonstrated in pilot scale tests which have also proven the feasibility of the peripheral pumping, agglomerating and handling equipment.

Also as a part of this study, the feasibility of producing a number of commercially useful and desirable products was demonstrated. Among these are: pressed and tamped brick and tile, extruded products such as ceramic pipe, and in particular, lightweight aggregate for both bulk concrete and lightweight block. The feasibility of producing lightweight aggregate continuously has been attempted. Concrete products of high quality have been produced in sufficient quantity in batch-wise steps, and these materials were obtained in reproducible qualities.

Florida phosphate deposits are strip-mined by first removing a sandy, generally unconsolidated over-burden and then stripping the matrix for processing. According to the Bureau of Mines (1), about nine million cubic yards of overburden must be removed to produce thirteen million cubic yards of matrix per year. Figure (1) shows a typical flow sheet of IMC mining operations.

Table I (2) shows the tonnages of phosphate rock mined and product produced in the United States. Most of this production is from Florida and approximately one-third of that is produced by IMC.

TABLE I

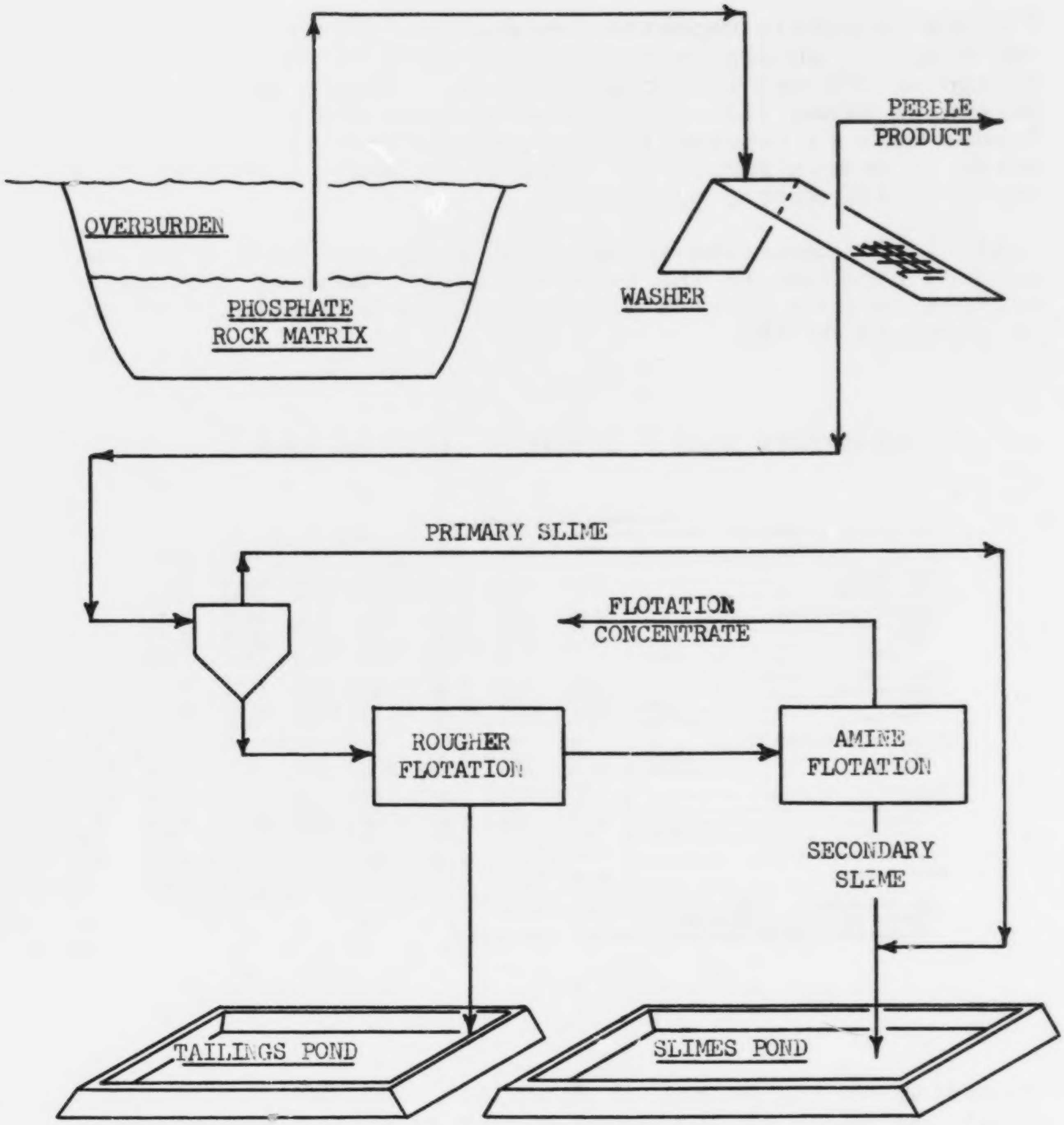
PHOSPHATE ROCK - SUMMARY: 1950 to 1968

[Quantities in thousands of short tons]

ITEM	1950	1955	1960	1965	1966	1967	1968
Mine production	(NA)	44,432	60,858	84,305	112,960	128,973	148,336
P_2O_5 content	(NA)	5,562	9,276	14,320	18,544	19,503	29,024
Marketable production	12,478	13,737	19,618	29,482	39,044	39,770	41,251
P_2O_5 content	3,994	4,353	6,006	9,432	12,112	12,464	12,843
Value ... $1,000	63,334	75,379	117,041	193,523	261,002	265,947	250,692
Per ton ... dollars	5.06	5.49	5.97	6.56	6.69	6.69	6.08
Sold or used by producers	11,484	14,768	19,266	29,039	36,443	37,835	37,319
P_2O_5 content	3,736	4,682	5,994	9,015	11,357	11,855	11,594
Value ... $1,000	59,028	82,904	115,363	188,590	245,182	251,163	228,347
Per ton ... dollars	5.14	5.61	5.99	6.49	6.73	6.64	6.12
Imports for consumption [1]	97	131	144	148	178	139	116
Value ... $1,000	[2] 1,114	2,703	3,754	2,980	4,256	3,261	2,679
Per ton ... dollars	[2] 11.48	20.63	26.07	20.14	23.91	23.46	23.09
Exports	1,971	2,445	4,473	7,323	9,248	10,072	12,099
P_2O_5 content	661	806	1,445	2,313	2,803	3,290	3,671
Value ... $1,000	10,365	14,269	26,632	51,109	65,952	69,479	75,653
Per ton ... dollars	5.26	5.84	5.95	6.98	7.13	6.90	6.25
Consumption, apparent [3]	9,611	12,454	14,937	21,864	27,373	27,902	25,336
World production	25,760	33,578	46,110	70,298	88,194	86,133	[4] 92,836

NA Not available. [1] Data on P_2O_5 content not available.
[2] Market value (price) at port of shipment.
[3] Amount sold or used plus imports minus exports. [4] Preliminary.

According to the Bureau of Mines (1), "Slimes constitute about one-third of the total matrix mined and amount to approximately 4 million tons per year with an approximate BPL value of 32%. About 30% of the BPL values of the matrix remains with the slimes. The plus 150-mesh material entrained in the slimes averages about 234,000 tons per year.



PEBBLE PRODUCT
OVERBURDEN
PHOSPHATE ROCK MATRIX
WASHER
PRIMARY SLIME
FLOTATION CONCENTRATE
ROUGHER FLOTATION
AMINE FLOTATION
SECONDARY SLIME
TAILINGS POND
SLIMES POND

FIGURE 1. FLOW DIAGRAM OF FLORIDA PHOSPHATE ROCK MINING OPERATIONS.

"The mineral composition of the slimes varies because the matrix is from different areas, depending on mining. Consequently, only a range of the composition can be established, as shown in Table II. Slimes produced also vary in chemical composition, as shown in Table III. A typical analysis and range is given as a guide rather than as a standard. The maximum range is based on analyses over a period of years."

TABLE II

APPROXIMATE MINERALOGICAL WEIGHT COMPOSITION OF PHOSPHATE SLIMES

Mineral	Percent
Carbonate fluorapatite	20-25
Quartz	30-35
Montmorillonite	20-25
Attapulgite	5-10
Wavellite	4- 6
Feldspar	2- 3
Heavy minerals	2- 3
Dolomite	1- 2
Miscellaneous	0- 1

TABLE III

CHEMICAL COMPOSITION OF PHOSPHATE SLIMES

Chemical	Typical analyses, percent	Range, percent
P_2O_5	9.06	9-17
SiO_2	45.68	31-46
Fe_2O_3	3.98	3- 7
Al_2O_3	8.51	6-18
CaO	14.00	14-23
MgO	1.13	1- 2
CO_2	.80	0- 1
F	.87	0- 1
LOI	10.60	9-16
BPL	19.88	19-37

Spectographic analyses of slimes typical of those used in these tests are shown in Table IV and a typical thermogram is shown in Figure (2). Studies showed that these slimes have properties comparable to many ceramic clays, exhibiting plastic behavior at approximately 60 wt% solids content, and that they can be extruded at about 70 wt% solids content. In firing tests sintering occurred over a reasonable temperature range of 1050° - 1150°C and color control can be achieved by controlling firing temperature. Slimes fired at the lower temperature are buff in color, progressing to deep red at the higher temperature. Initial experiments indicated shrinkage during firing which may lead to surface checking. This may be alleviated by addition of a presintered material (grog) or sand.

X-ray analysis as shown in Table IV was conducted on the raw dried slimes. This investigation confirmed past reports (3, 4) that variations in the mineralogy are to be expected.

TABLE IV

SPECTROGRAPHIC ANALYSIS OF PHOSPHATE SLIME

Metal	Amount(1)	Remarks
Iron	>1	Very strong
Silicon	>1	--
Aluminum	>1	Strong
Calcium	>1	Strong
Phosphorus	>1	--
Magnesium	>1	Strong
Titanium	~ 1	--
Chromium	<1(2)	Definite
Sodium	<1	--
Manganese	<1	--
Strontium	<1	--
Barium	<1	Weak
Zirconium	<1	Weak
Nickel	(.01)	--
Vanadium	(.01)	--
Zinc	(.01)	--
Copper	(.001)	Definite
Berryllium	(.001)	Definite
Potassium	Trace	--
Cerium	Trace?	One line
Yttrium	Trace?	One line
Lead	?(3)	--
Tin	?	--
Lithium	?	--
Uranium	?	Much interference(4)
Boron	-	Not detected

(1) Used a ± 1% standard
(2) Less than 1%, greater than 0%
(3) Questionable
(4) Better separation can be obtained by second order spectral analysis

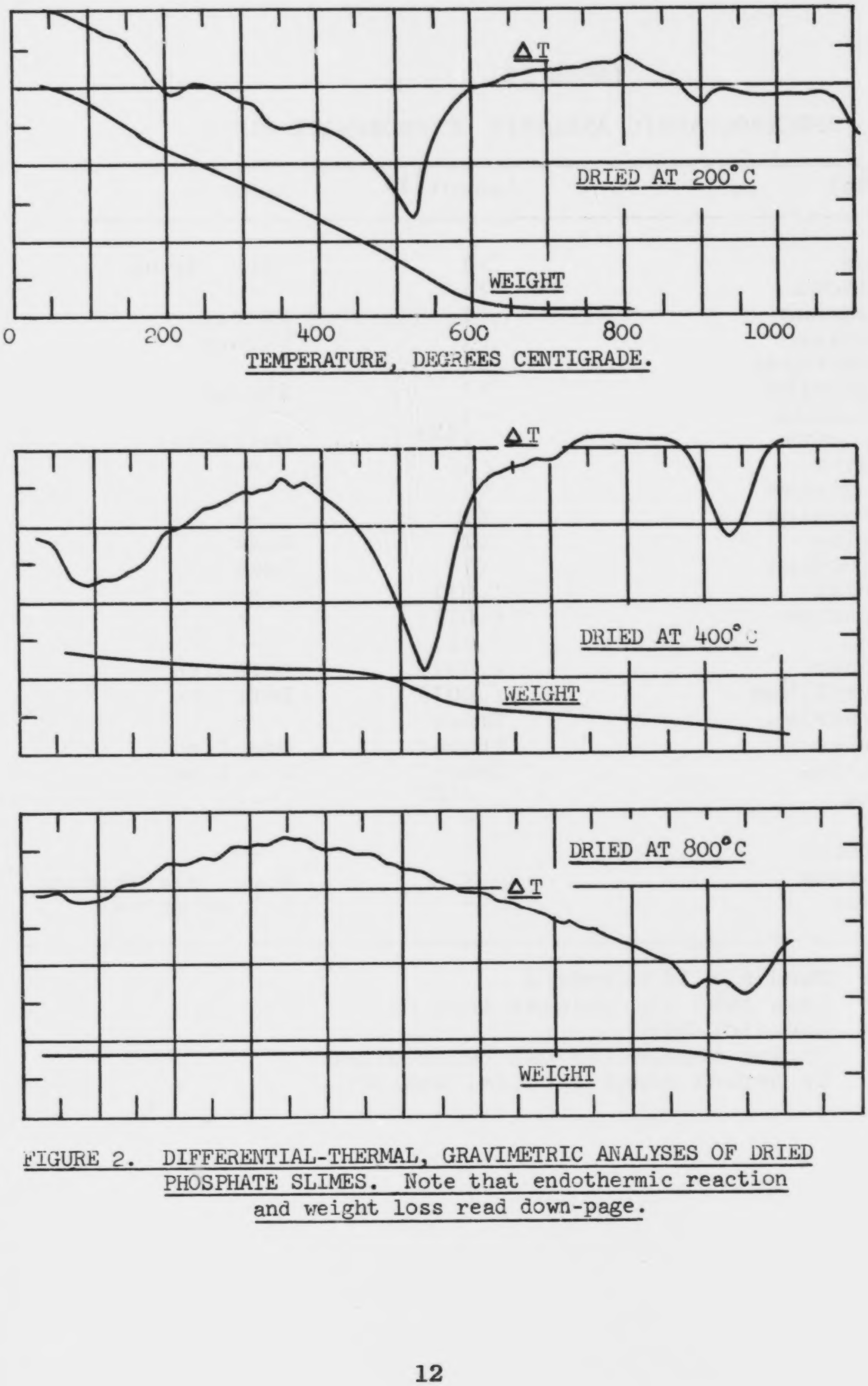


FIGURE 2. DIFFERENTIAL-THERMAL, GRAVIMETRIC ANALYSES OF DRIED PHOSPHATE SLIMES. Note that endothermic reaction and weight loss read down-page.

The results of chemical analysis are shown in Table V. Previous analyses are also shown confirming the indications above that the composition of these slimes are variable and may require adjustment of composition during processing of a ceramic body.

TABLE V

CHEMICAL ANALYSIS OF PHOSPHATE SLIMES, DRY BASIS

Constituent	Amount, %				
	(1)	(2)	(3)	(4)	(5)
SiO_2	27.9	32.6	34.1	41.8	29.0
Al_2O_3	16.5	16.2	16.2	7.2	16.8
CaO	16.5	18.4	16.6	11.7	11.9
P_2O_5	14.2	11.8	12.5	9.8	13.1
MgO	1.85	2.3	2.0	1.8	1.9
Fe_2O_3	6.60	4.8	4.0	3.3	7.2
MnO	0.08	-	-	-	-
TiO_2	0.64	-	-	-	-
C	0.55	1.3	0.9	-	-
CO_2	1.10	1.4	2.0	-	-
Na_2O	0.36	-	-	-	-
K_2O	0.61	-	-	-	-
H_2O^+	6.48	12.8(6)	14.1(6)	12.6(6)	16.3(6)
H_2O^-	4.37	-	-	-	-
F	1.38	2.7	1.8	2.2	2.2

(1) IITRI Analysis of slime stored at Noralyn, Florida.
(2) 1 year old pond, ~14% solids, M. H. Stanczyk and I. L. Feld, "Electro-Dewatering Tests of Florida Phosphate Rock Slime," Bureau of Mines RI 6451 (1964).
(3) Undetermined age, ~17% solids.
(4) Undetermined age, ~30% solids.
(5) 2 year old pond, 27% solids.
(6) Loss on ignition.

Pyrometric Cone Equivalent tests (see Glossary) showed that initial deformation occurred at about 1145°C. Maximum deformation occurred at 1210°C and is equivalent to a melting point. During firing, the color of the ceramic body darkened progressively to a dark brown at melting. These tests also suggested the possibility that some types of phosphate slimes may bloat or foam.

The Atterberg test (5), which determined the general workability of a clay and the amount of water permissible for plasticity to occur, was used to approximate the conditions for handling unfired ceramics. This indicated that plasticity occurs in the range of 69-75 wt% water added to the slime solids. Based on the total water-solids slurry, this is equivalent to a solids content of 57-62.5 wt%.

The amount of solids in slurries obtained from the Noralyn site ranged from 8 to 12% and initial tests were carried out on both pond-stored and washer-discharged slimes. Subsequent slurries were pre-thickened by liquid withdrawal to expedite dewatering and drying for processing experiments. These slimes displayed a pH variation of 7.0 to 8.5.

Measurements of the rheological behavior were performed to characterize handling characteristics. These indicated that grey pond-stored slimes are thixotropic, whereas the fresh washer-discharged slimes are plastic at low-shear and dilatent at higher shear rates. Thixotropy is desirable for foaming because shear forces increase fluidity. In contrast, dilatency is generally undesirable because such stresses tend to make the material less workable.

The viscosity of a 12.4% solids slurry was measured with and without deflocculant. These limited results, shown in Table VI, indicate that these slimes slurries can be efficiently deflocculated.

TABLE VI

VISCOSITY* OF PHOSPHATE SLIME MIXTURES (12.4% SOLIDS)

Additive	CPS x 10^3*
None	63.2
0.2% Sodium Silicate	30.4
0.2% Na_2CO_3	82.4

*No. 3 spindle at 0.3 RPM
Brookfield Viscometer Model LVT

Additional characterization studies included settling and thermal properties of these slimes. Table VII shows typical settling velocities and indicates that fluid-bed drying increases settling velocities two orders of magnitude. It suggests that this drying may have altered particle size or charge.

TABLE VII

PROPERTIES OF RAW AND DRIED SLIMES DILUTED TO 5% SOLIDS SUSPENSIONS

Slime No.*	Settling Rate in./hr.	pH	Observations
1	0.104	5	Buff
2	0.021	5	Grey
3	0.125	5	Light and dark buff
4	0.042	5-6	Brown
5	0.042	5	Light and dark buff
6	0.042	5	Light and dark buff
7	3.5	5	Coarse grain, buff
8	3.5	6	Coarse grain, buff

* First six specimens were 35% solids raw slimes; Nos. 7 and 8 were fluid-bed dried.

Thermal conductivity for fluid-bed dried product was measured as K - 1.13 BTU/hr/^{o}F/ft^{2}/in. at 70^{o}F mean temperature on material containing about 8% moisture in particles less than 1/4 in. (unit weight 60 lb/ft^{3}). Specific heat of (mean temperature of 95^{o}F) a -8+16 mesh fraction of fluid-bed dried slime measured 0.28 BTU/lb/^{o}F giving a calculated value for bone dry slime of 0.22 BTU/lb/^{o}F. Fired pellets (-4+8 mesh fraction) were found to have a specific heat of 0.24 BTU/lb/^{o}F. Commercial LWA (Materialite) had a specific heat of 0.25 BTU/lb/^{o}F for -3/8+4 mesh particles. All of these specific heat measurements compare normally with mixed oxides.

Slime wastes are normally discharged into large settling ponds from which some clear water can be recovered and re-used in the processing plant. Since about 1.25 acre-feet of wet slimes are produced per acre foot of matrix mined, the settling ponds are located over mined-out areas with above-grade dams around them. The Bureau of Mines (1) estimated that the capital investment, for a mine the size of IMC's Noralyn Operation, is about 1.66 million dollars and the net operating cost is about $0.245 per ton.

From these settling ponds, only a fraction of the contained water can be separated. Figure (3) shows that even after 20 to 30 years of quiescent settling, only about 15% of the water originally present separates and the pond stabilizes at about 20% solids making land so occupied useless.

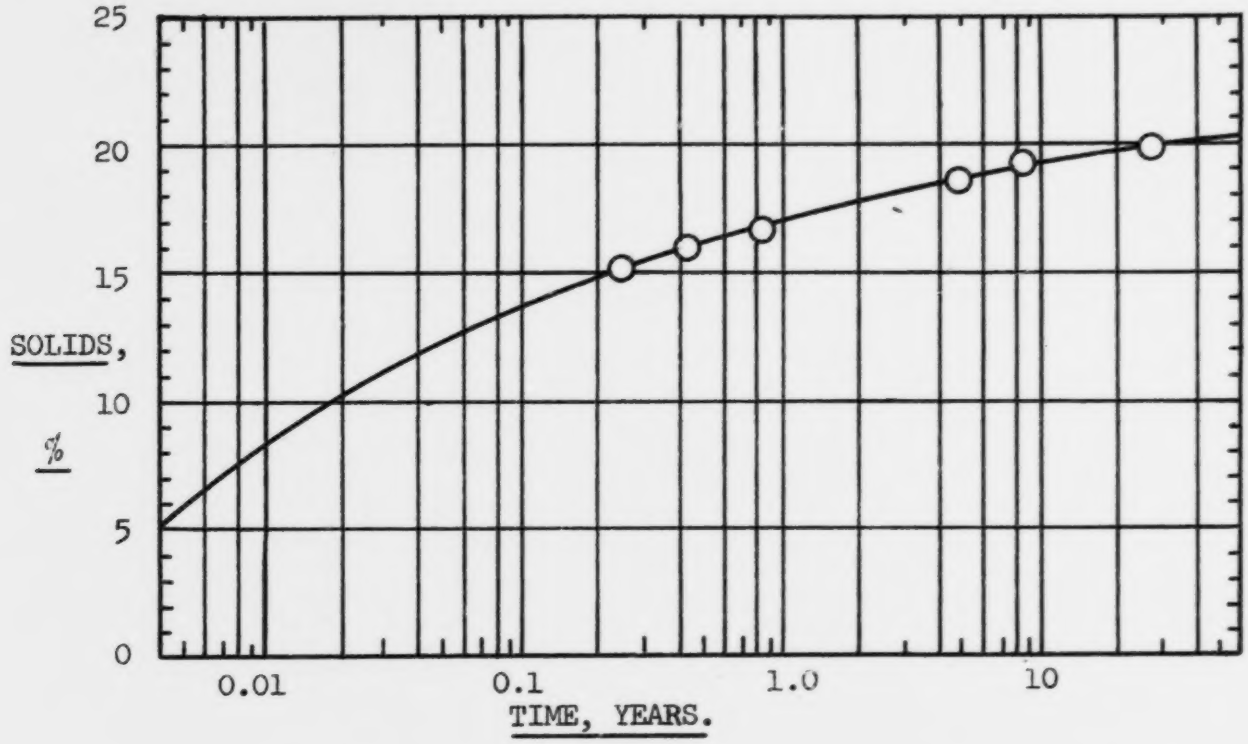


FIGURE 3. RATE OF CONSOLIDATION OF PHOSPHATE SLIMES, TYPICAL.

In addition, there is a continuing requirement for new land for disposal-sites in a market of rapidly rising land-values. There are increasing demands for water to replace that which is tied up in these ponds in spite of potential water shortages. Finally, there is the ever present danger of dam failure which could result in severe pollution of rivers, streams, ground water resources, and residential and recreational areas.

While costs of present disposal methods are increasing, the phosphate industry is being subjected to other severe economic pressures. Unless the phosphate rock industry can be given relief in the form of an economic solution to the disposal of these slimes, it will undoubtedly suffer severe losses.

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DEVELOPMENT OF THE PROGRAM

The primary objective of the project was to demonstrate that slimes could be removed from the slime ponds and dried economically. A second objective of equal importance was to show that these dry slimes could be utilized in building products. A third objective, of lower priority, was to review all literature and reports developed over the last 40 years and, with the aid of additional laboratory work, fully characterize the phosphate slimes in terms of chemical, physical and thermal properties.

The primary objective, the production of dry slime powders, was demonstrated and is discussed in detail in a separate section of this report. The properties of the clay slimes was investigated and was discussed in the previous section.

Utilization of the dry slime powders will be discussed in the section that follows. An underlying objective was utilization of large volumes of the slimes in order to eliminate storage of phosphate slimes, and this represents the driving force and motivation for this project. Dry slimes were utilized in a number of potential building products. Concurrent with this, a preliminary market study was made of all of the building products and the market potential for phosphate slime was estimated for each building application. The results of these concurrent investigations are discussed below:

AGGREGATES

The production of lightweight aggregates was found to be the most promising potential end-use for phosphate slimes in building product applications. Lightweight aggregates showed the highest potential for immediate acceptance in lightweight structural concrete. In addition, aggregates represented the largest market for building products in the Florida area. This application could consume nearly 8 million tons per year of dry slime solids. This, in turn, would release nearly 20 million tons per year (or nearly 5 billion gallons) of locked-up water in the slime ponds for ultimate re-use.

In view of the large market potential for aggregates, the possibility for immediate market acceptance and the fact that aggregates could utilize over 20% of the industry's total annual production of slimes, it was decided to apply maximum effort to this phase of the utilization program. A detailed discussion of the aggregate investigation is presented in separate sections of this report.

BRICKS

Bricks were produced from dry phosphate slimes. In initial tests heat requirement was excessive and distortion and surface imperfections of the test product were observed. New formulations containing slimes plus grog (i.e. sand) were tested indicating a substantial reduction in firing time along with elimination of distortion and a reduction in surface imperfections.

At this stage of the program the production of bricks was screened, evaluated and rejected for the following reasons:

(a) The total market for phosphate slime base red bricks in the Florida market was very limited and did not warrant added research efforts.

(b) Preliminary cost estimates placed the cost of red bricks based on phosphate slimes at about 15¢ per brick. This was considered to be excessive or uneconomical for sales in the limited Florida market.

(c) The surface and distortion problems could be solved with additional research effort, but the cost to blend an additive such as grog (i.e. sand) was found to be unattractive.

When high volume markets for building products based on slimes have been developed through other products, it may be practical to reconsider brick as an application for dry phosphate slimes.

PIPE

Pipe sections based on dry slimes were produced and fired at 1100°C. The resultant test pipe exhibited several disadvantages including excessive firing time, dimensional instability and/or distortions. Efforts were made to correct these problems by developing new formulations containing grog (i.e. sand). As a result, firing times were reduced and distortions were eliminated.

Compression tests indicated that the pipe had a compressive strength of nearly 1600 pounds per linear foot and indicates that the pipe would pass the ASTM C330 specifications shown in Table VIII below.

TABLE VIII

CRUSHING STRENGTH REQUIREMENTS FOR STANDARD STRENGTH CLAY PIPE
(ASTM C13, "Standard Strength Clay Sewer Pipe")

Size, inches	Minimum Strength, lb/linear ft
4	1200
6	1200
8	1400
10	1600
12	1800

At this stage of the project, production of pipe was re-evaluated and was rejected for the following reasons:

The total market for phosphate slime based pipe in the Florida market was quite limited and would not warrant added research effort at this time.

The various problems associated with pipe based on phosphate slimes can probably be solved at reasonable cost with added research. However, the limited markets for pipe did not warrant this added research effort as a part of this project in view of a substantially larger market offered by aggregate made from phosphate slimes.

TILE

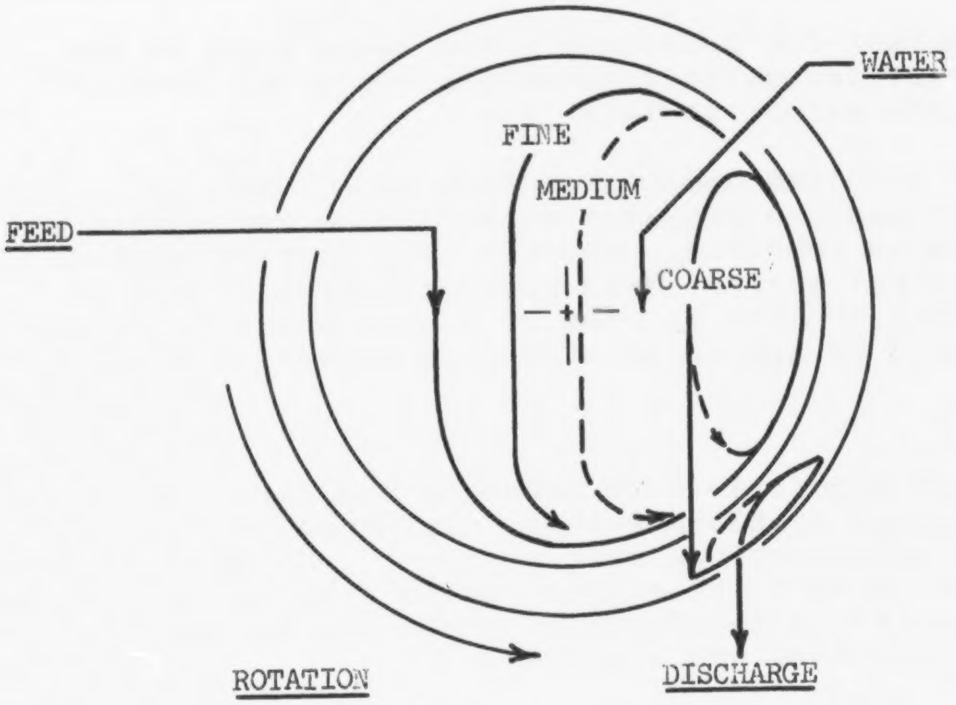
Samples of pressed tile were produced and fired in a kiln. Technical problems such as shrinkage, distortion and surface imperfections were apparent. No major efforts were made to correct these problems in view of the limited market potential in the Florida market and further research on tile applications was abandoned.

FOAMED BODIES

Foamed bodies made from slimes did not exhibit the strength and drying characteristics of successfully foamed red muds (4). In view of limited markets and low product quality, no further work was conducted in this area.

FERTILIZER APPLICATIONS

Tests were made to determine the utilization of phosphate slimes as a potential binder in the granulation or agglomeration of fertilizer materials including: purified potassium chloride, two grades of muriate of potash, triple super-phosphate, and potassium sulfate. Each was ground to -100 mesh, and then agglomerated in a 54 x 9 in. disc agglomerator, as shown in Figure 4. Additional tests were performed using a 4-foot pan agglomerator in the Nitrin plant of IMC using commercial grades of potassium sulfate and an undersize-standard white muriate of potash product. Agglomerates were produced with and without addition of slimes as a binder. These agglomerates did not meet size specifications and were in general unsatisfactory as a granular fertilizer product.



Figue 4. AGGLOMERATION AND SIZE-CLASSIFICATION IN A ROTATING DISC

LIGHTWEIGHT AGGREGATE (OR LWA)

Concurrent with the studies of alternatives described above, considerable effort had already gone into investigation of the possibilities of producing a lightweight aggregate. About half-way through this project, it became apparent that this would be the most likely candidate of all the alternatives under investigation to prove feasible, profitable, and amenable to production at a relatively early time.

Preliminary market studies showed that production of lightweight aggregate may prove feasible and profitable in the Florida area, especially considering volume of intended usage. In 1969, consumption of LWA in Florida was of the order of 3,000,000 to 4,000,000 tons. With the projected boom in housing and construction industry in Florida, this market for LWA should double in the next decade. There are apparently few local competitors and the geographical location of a future plant in The Bone Valley area is within easy access to a large portion of the State. In addition, the current sale price for a variety of LWA is about $7.00/ton.

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PREPARATION OF LIGHTWEIGHT AGGREGATE

There are four major unit operations or processing steps necessary for the production of lightweight aggregate from phosphate slimes. These are defined as: material handling, drying, agglomeration, and kilning.

The first problem to be solved was to develop a feasible method of transferring wet phosphate slimes, with a solids content ranging from 20 to 35%, to a process unit for treatment including drying. The second step, undoubtedly the most critical from an economic viewpoint, was drying. Drying of partially dewatered slimes is the area in which all previously proposed projects have failed due to poor economics. Each of the unit operations necessary for the production of lightweight aggregate is discussed in greater detail below.

Material Handling

It was concluded early in the study that it would be economically feasible to transfer wet slimes from the slime pond to a processing plant located adjacent to the slime pond by the use of conventional drag-line equipment. However, additional methods of material handling were also investigated and the possibility of pumping slimes was investigated in detail. A number of pumps of different types, such as gear, centrifugal and positive displacement pumps were tested, most of which proved impractical. However, two pumps (3) appeared to be suitable for moving phosphate slimes of high solids content.

A modified MOYNO* was found to be the most reliable method of moving slimes. A pump manufactured by the Wilden Division of the Worthington Pump Corporation* was also found to be equally reliable. This is a submersible diaphragm pump originally designed for use as a drill mud-pump in oil field operations. It is designed to be placed into the mud (i.e. installed below the surface of the mud) or in our case, slimes. Since the suction is submerged, NPSH (Net Positive Suction Head) is always positive.

* Mention of trade names of commercial products is for identification only and does not constitute an endorsement or recommendation by the Environmental Protection Agency.

The drying, agglomeration and kilning of the dry slime powders or pellets was carried out in three individual unit operations.

Drying

A Pilot Plant was built at Erie, Illinois for testing these three unit operations, as shown schematically in Figure 5. The equipment in this Pilot Plant included:

(1) Vibrating screens

(2) Crushers (2)

(3) Four-foot disc agglomerator

(4) Two rotary direct fired drying drums

(5) Large elevator

(6) Structural steel, platforms, railings, etc.

Added details are shown in Figure 6. Provision was made in the Pilot Plant to permit later modification to produce aggregates as shown in Figure 7.

Various methods of slime dewatering were investigated, including leaching, leach-electrolysis, curing and baking, ion exchange, electro-osmosis, filtration and drying in various types of dryers. Investigation of dryers confirmed the findings of past researches to the effect that the drying problem was practically insurmountable in drying slimes containing 20% to 35% solids. Rotary dryers were unable to handle the semi-plastic slimes which tend to bridge and clog the dryer, requiring frequent and costly maintenance. Heat and mass transfer were hampered by the excess fluidity of the feed. The major disadvantage of rotary dryers is their low thermal efficiency (6) as illustrated in Table IX. Spray drying was also considered. However, the costs (6) as shown in Table X, were excessive due to the high fuel cost of about $20.00 per ton of dry solids.

Attention was centered on a relatively new type of fluid-bed dryer that has been in commercial development in recent years. This dryer is shown schematically in Figure 8. Hot gases are passed through the bottom of the dryer into the bed of material to be dried, fluidizing those materials. These hot gases remove the moisture and carry it out through the overhead outlet. The unique

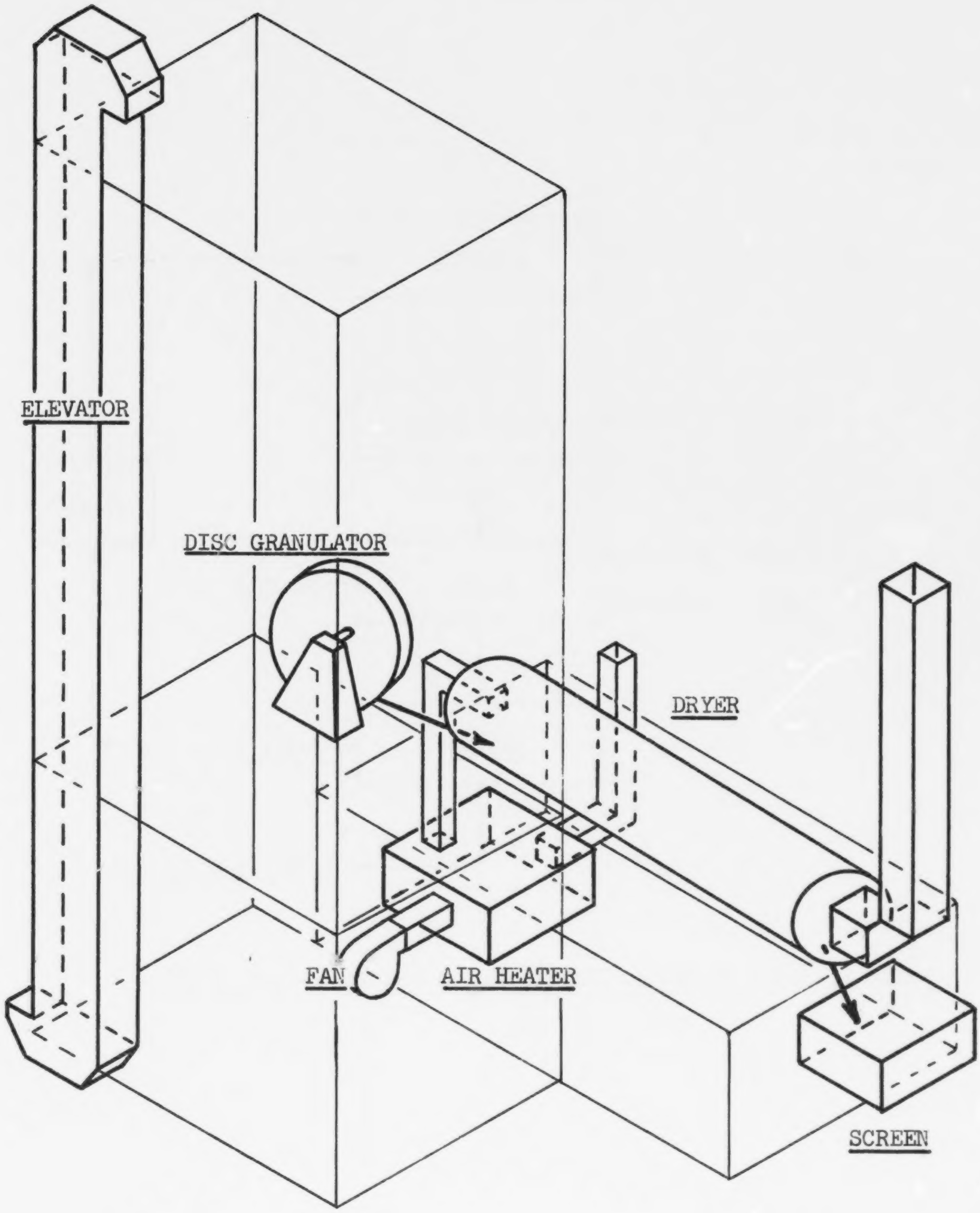
ELEVATOR
DISC GRANULATOR
DRYER
FAN
AIR HEATER
SCREEN

FIGURE 5. GENERAL ARRANGEMENT, LIGHTWEIGHT AGGREGATE PILOT PLANT.

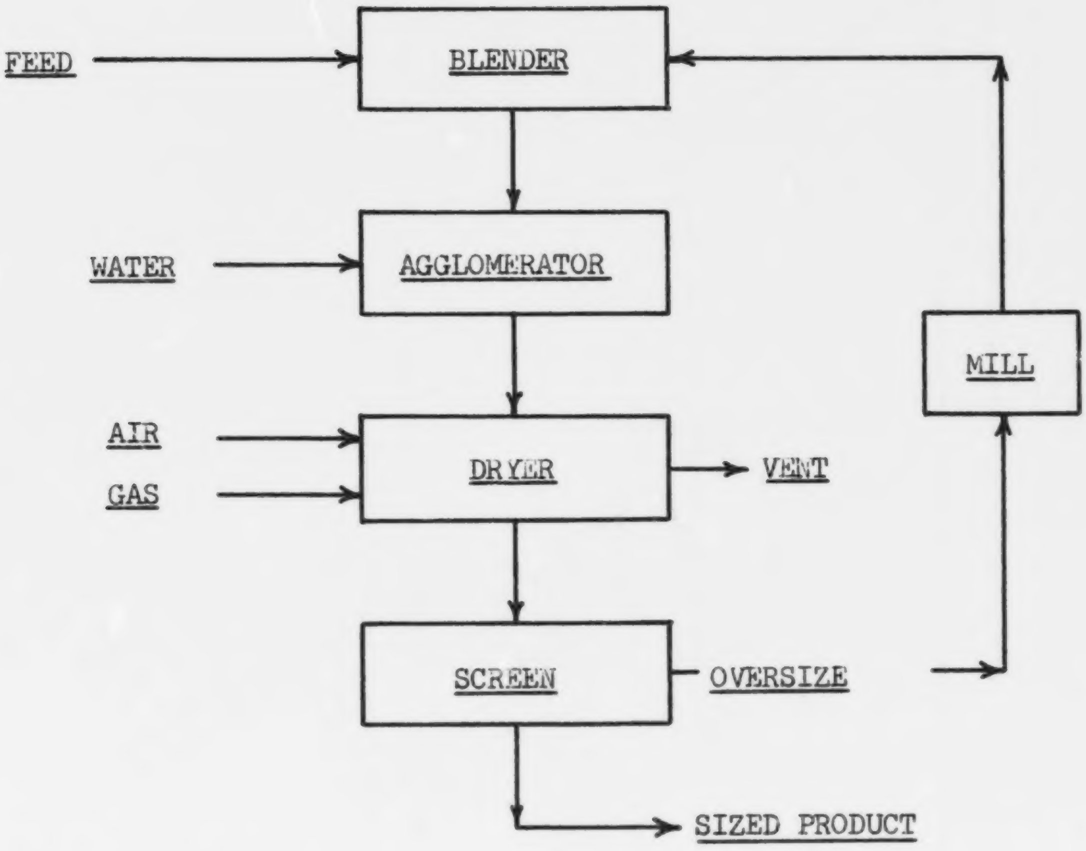
FEED
BLENDER
WATER
AGGLOMERATOR
MILL
AIR
GAS
DRYER
VENT
SCREEN
OVERSIZE
SIZED PRODUCT

FIGURE 6. FLOW DIAGRAM, LIGHTWEIGHT AGGREGATE PILOT PLANT.

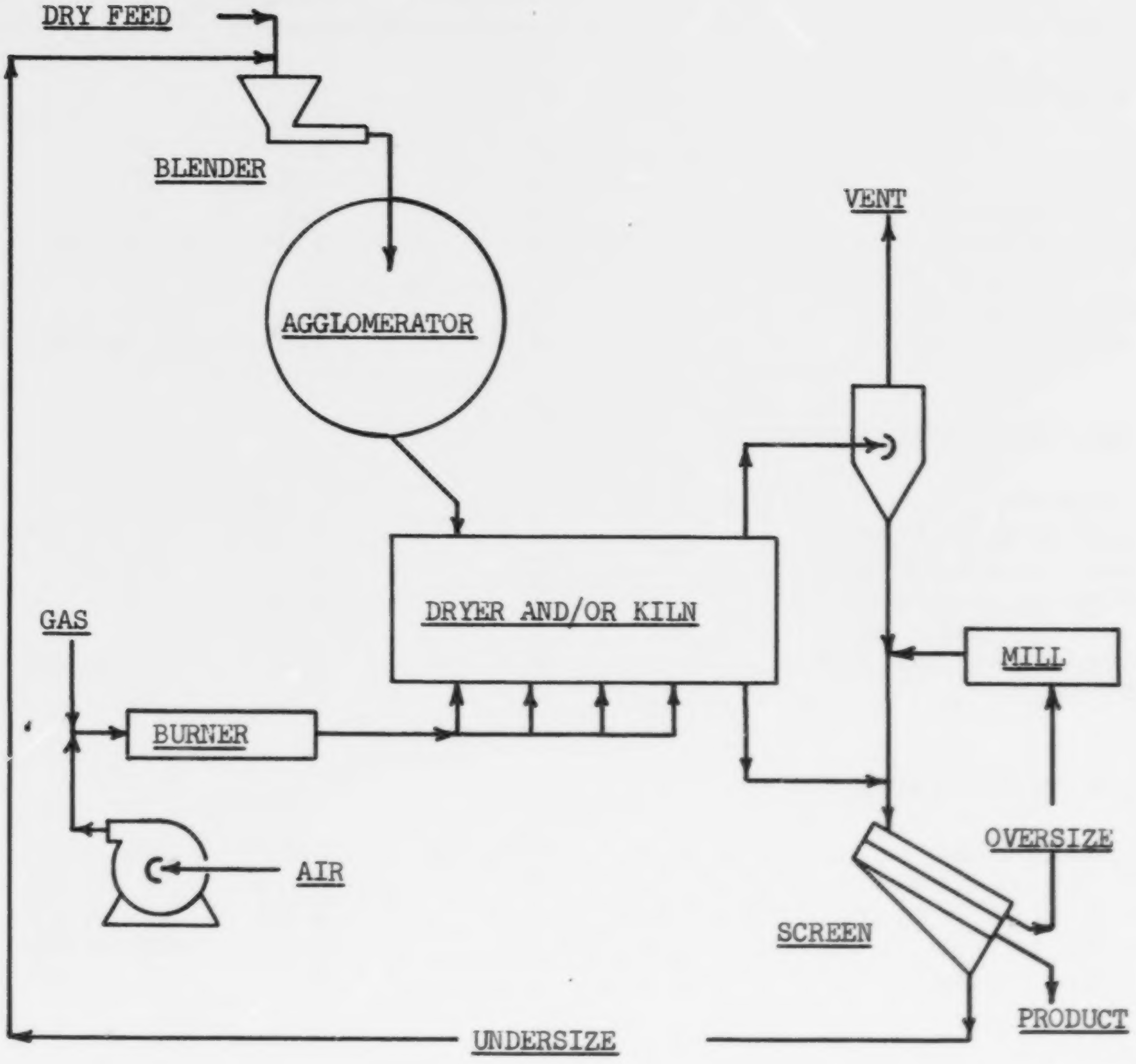
DRY FEED
BLENDER
AGGLOMERATOR
VENT
DRYER AND/OR KILN
GAS
BURNER
MILL
AIR
OVERSIZE
SCREEN
PRODUCT
UNDERSIZE

FIGURE 7. FLOW DIAGRAM FOR PROPOSED AGGREGATION PILOT PLANT.

TABLE IX

TYPICAL PERFORMANCE OF DIRECT-HEAT ROTARY DRYERS

Material Dried	Moisture Content,% (Wet Basis) Initial	Moisture Content,% (Wet Basis) Final	Heat Efficiency, %
HIGH-TEMPERATURE			
Sand	10	0.5	61
Stone	6	0.5	65
Fluorspar	6	0.5	59
Sodium chloride . . . . . (vacuum salt)	3	0.04	70 to 80
Sodium sulfate	6	0.1	60
Ilmenite ore	6	0.2	60 to 65
MEDIUM-TEMPERATURE			
Copperas	7	1 (moles)	55
Ammonium sulfate	3	0.10	50 to 60
Cellulose acetate	60	0.5	51
Sodium chloride . . . . . (grainer salt)	25	0.06	35
Cast iron borings	6	0.5	50 to 60
Styrene	5	0.1	45
LOW-TEMPERATURE			
Oxalic acid	5	0.2	29
Vinyl resins	30	1	50 to 55
Ammonium nitrate prills .	4	0.25	30 to 35
Urea prills	2	0.2	20 to 30
Urea crystals	3	0.1	50 to 55

TABLE X

ECONOMICS OF SPRAY DRYING

	Small Dryers		Large Dryers	
	Typical	High	Typical	High
Operating temperature, °F..........	500	1,000	500	1,000
Evaporative capacity, lb water/hr..	400	1,000	6,500	16,000
Heat requirement, BTU/hr...........	1,200,000	2,200,000	20,000,000	35,000,000
Power requirement, hp..............	20	30	220	280
Approximate equipment cost, \$*.....	36,000	38,000	190,000	210,000
Typical operating cost ¢/lb↑.......	1.2	0.6	0.4	0.3

* Equipment costs are FOB shop.

↑ Operating costs are 6/lb. of water evaporated, and include equipment, power, labor, and fuel costs.

June 19, 1967 -
Chemical Engineering

100 lbs. feed contains 75 lbs. H_2O and 25 lbs. solids.

1 ton of feed contains 1500 lbs. H_2O and 500 lbs. solids.

If it costs 0.3¢/lb. H_2O evaporated, then 1500 x .003 = \$4.50/ton feed

or $$\frac{\$4.50}{500\text{ lbs. solids}} = \$19.20/\text{ton of dry solids.}$$

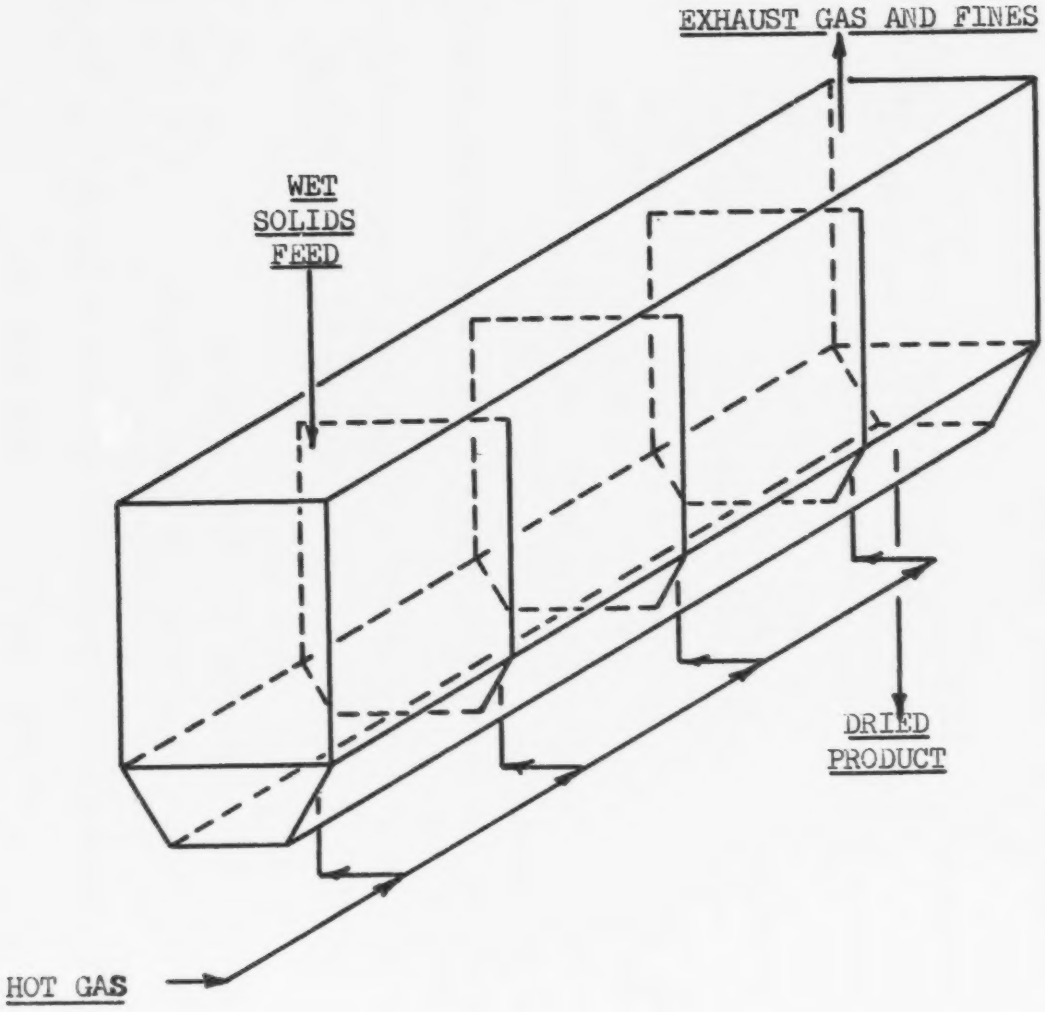
EXHAUST GAS AND FINES
WET SOLIDS FEED
DRIED PRODUCT
HOT GAS

FIGURE 8. SCHEMATIC DIAGRAM OF FLUID-BED DRYER.

(Fluid-bed dryer of Tailor & Company,* Bettendorf, Iowa was used in all these tests.)

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* Mention of trade names of commercial products is for identification only and does not constitute an endorsement or recommendation by the Environmental Protection Agency.

feature of this dryer is that both the product and the effluent gases leave the dryer at low temperature; thus, most of the heat imput is consumed in the drying operation. Low heat losses result in very high thermal efficiency which can range as high as 80% to 90%. The development of this dryer along with modifications installed by the manufacturer to meet the special needs encountered in drying phosphate slimes, was of great value. The high efficiency of this dryer makes the drying of phosphate slimes economically feasible.

Extensive tests were conducted on this dryer in the Erie, Illinois test site. The layout of the dryer is shown in Figure 9 and the results of these test runs are summarized in Table XI.

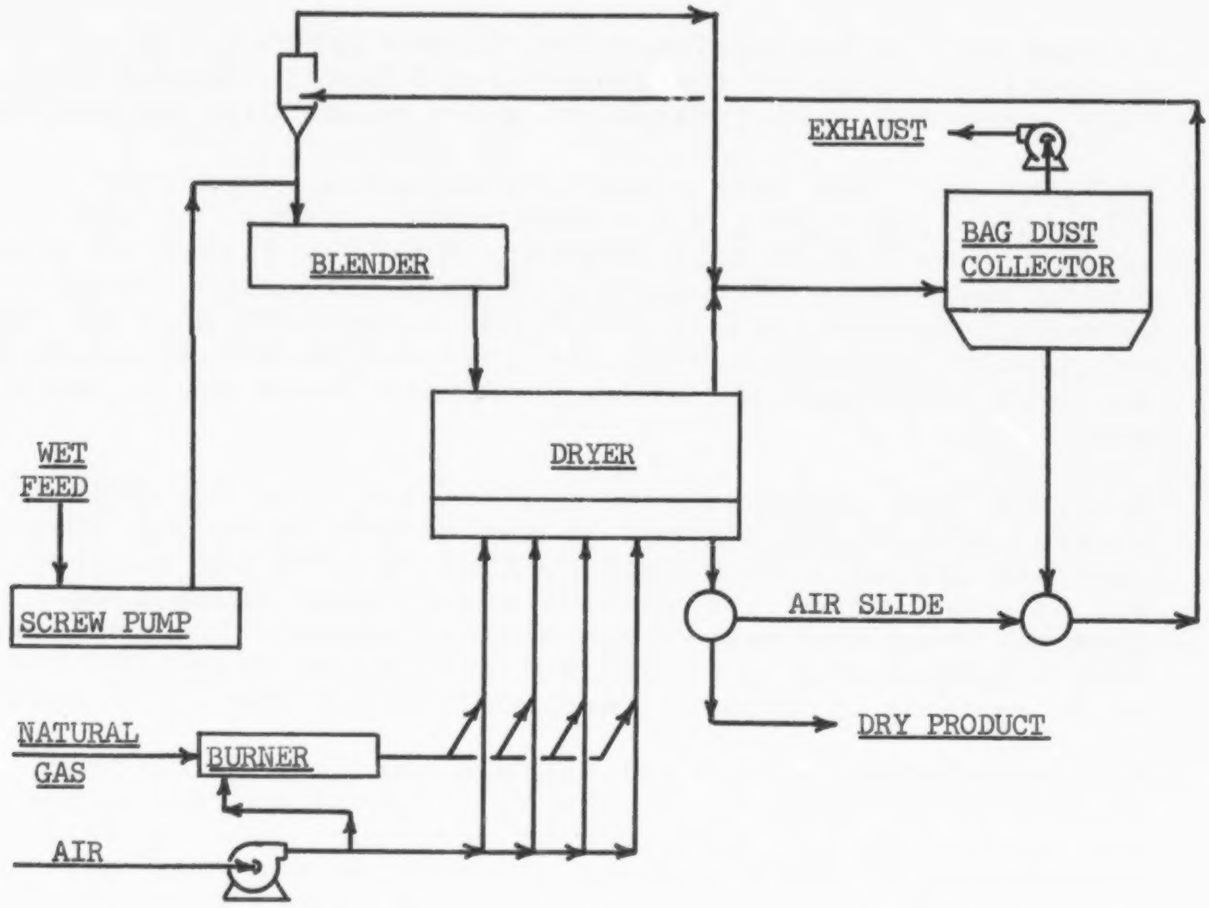

EXHAUST
BAG DUST COLLECTOR
BLENDER
DRYER
WET FEED
SCREW PUMP
AIR SLIDE
DRY PRODUCT
NATURAL GAS
BURNER
AIR

FIGURE 9. ARRANGEMENT OF EXPERIMENTAL FLUID-BED DRYER SYSTEM.

TABLE XI

SUMMARY OF TEST RESULTS ON FLUID-BED DRYER MARCH - JUNE, 1970

Run No.	Solids in °F	Solids Out °F	% H_2O In Feed	% H_2O Product	Drying Eff.%	Lbs/hr Wet Feed	Oper. Factor
2	65	122	25.7	6.7	52	150	75
3	66.3	162	29.5	3.4	62	169	80
4	55	111	21.2	9.6	72	246	90
5	83.8	143.6	23.3	4.9	70	226	82

In addition, dried agglomerated slimes product was successfully made at the Erie Pilot Plant in October of 1970 using the 4-foot diameter pilot plant disc granulator.

Analysis of these data shows, as expected, that both efficiency and capacity of this dryer increase as the operating reliability increases. Also, as Figure 10 shows, drying efficiency increases at higher throughput rates because constant heat losses become a smaller part of the total load. The data indicate that drying efficiencies of 80 - 90% can reasonably be expected in large scale equipment.

Expected fuel costs were calculated assuming the 90% thermal efficiency claimed by the manufacturer and the cost and properties of fuel in Florida (37¢ per million BTU of fuel value). Figure 11 shows these calculated fuel costs at various slimes-solids contents and indicates that complete drying of 25% solids feed material would be $3.20 per ton of dried slimes solids, for fuel cost alone.

The calculated theoretical maximum throughput for this test dryer is shown in Figure 12. The pilot test dryer was limited by its materials of construction to a maximum temperature of 550°F whereas it would be expected that a commercial dryer designed for these purposes would operate at 1000° to 1500°F. It would therefore have a capacity of as much as 2½ times the rated capacity of the present test unit on a lbs/hr/ft² basis. An approximate

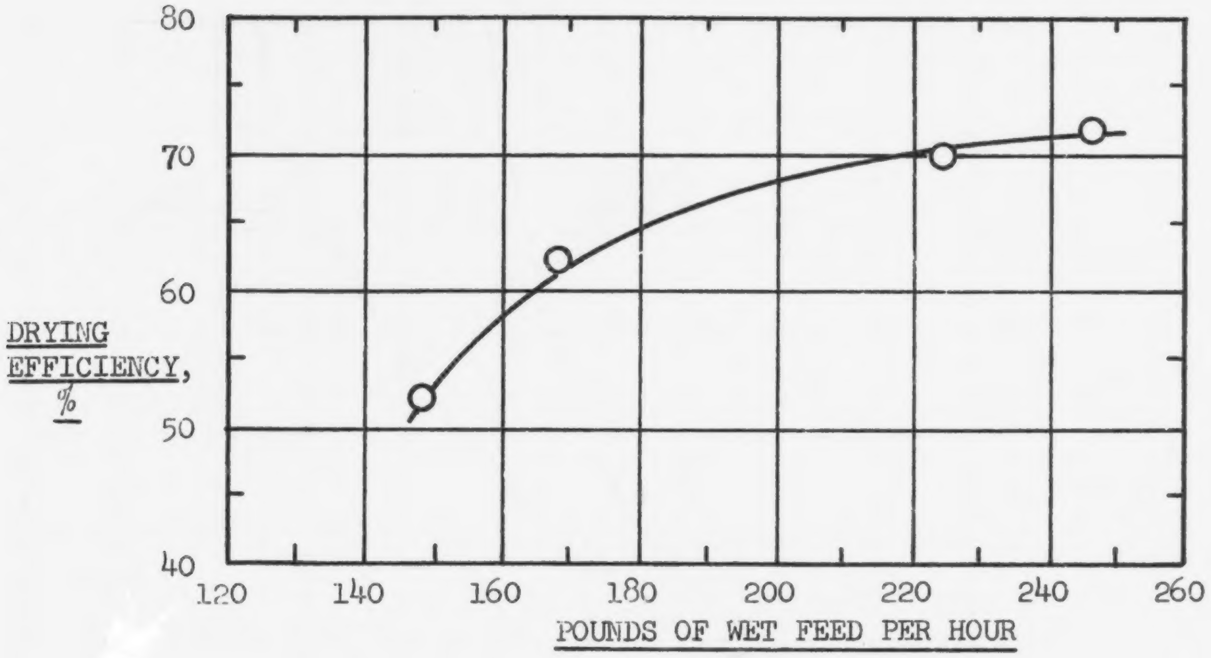


FIGURE 10. EFFECT OF THROUGH-PUT ON THE EFFICIENCY OF DRYING PHOSPHATE SLIMES IN THE FLUID-BED DRYER.

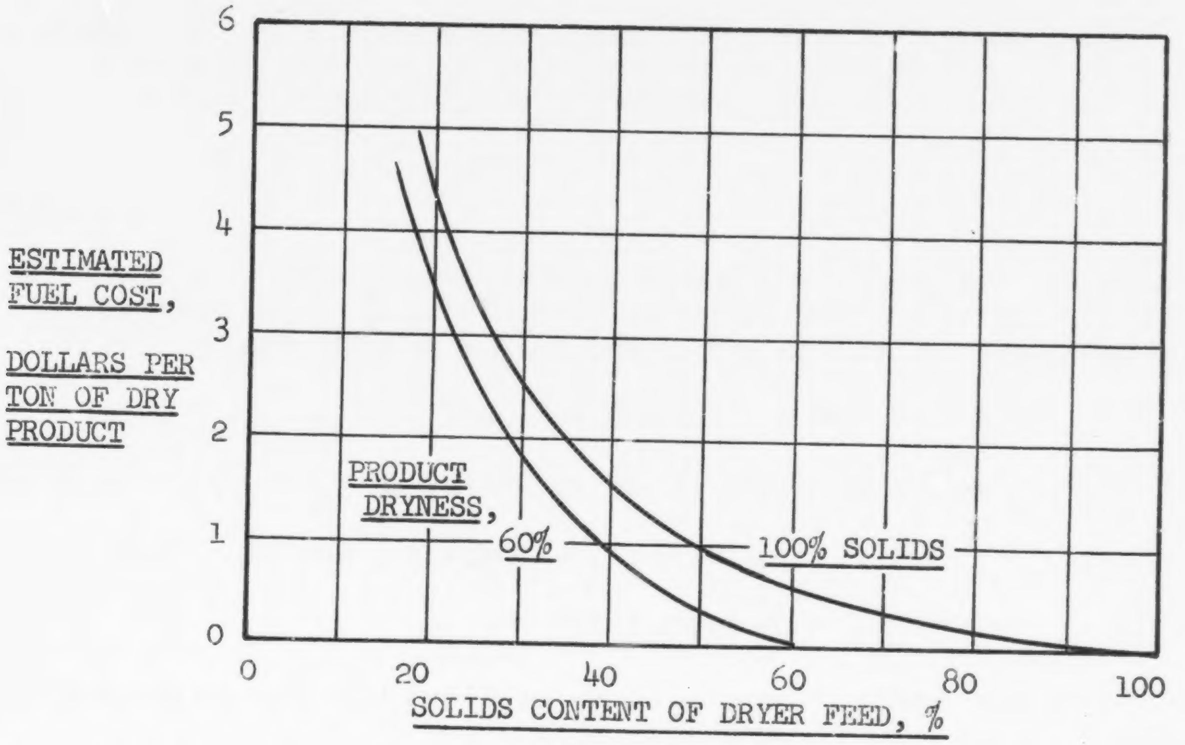


FIGURE 11. ESTIMATED COST OF FUEL TO DRY PHOSPHATE SLIMES IN A FLUID-BED DRYER.
(Calculated at 90% thermal efficiency, 140,000 BTU/gal. of fuel oil at 5.2¢/gal.

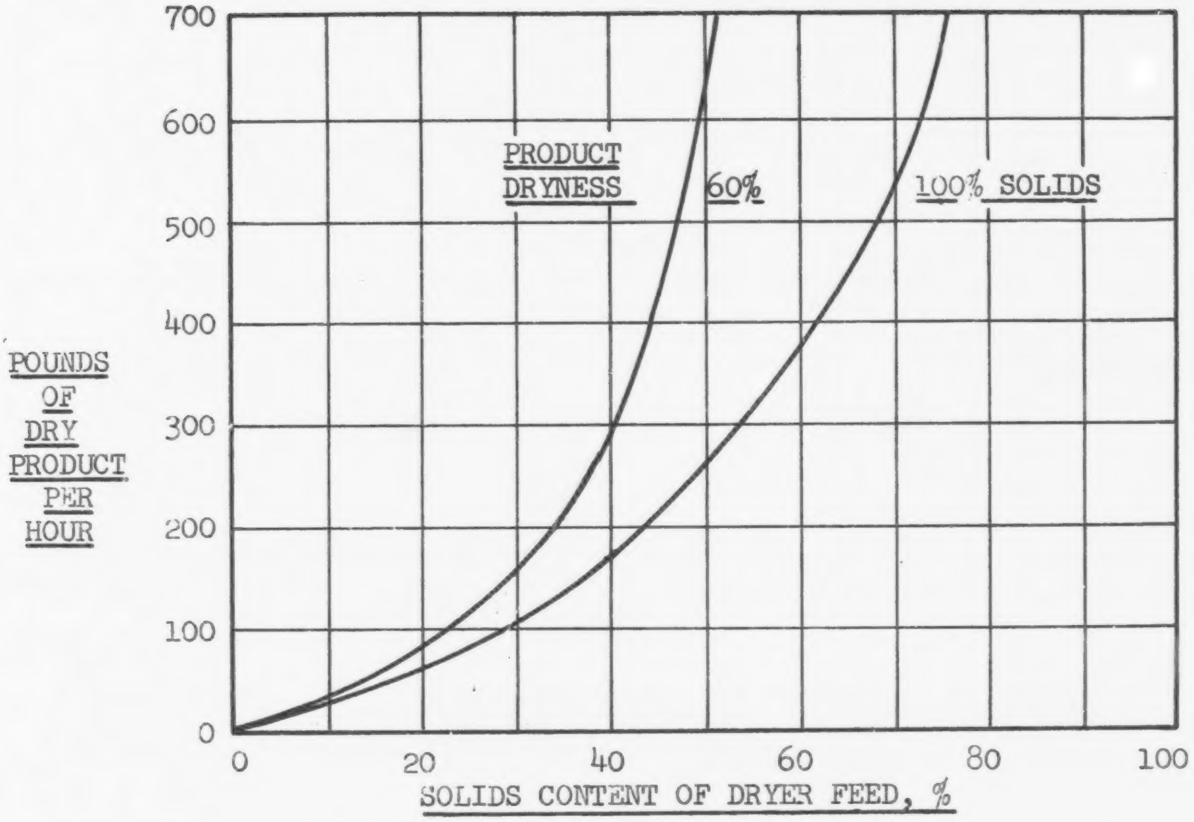


FIGURE 12. THEORETICAL CAPACITY OF 2 SQ. FT. FLUID-BED DRYER.
Determined for the measured maximum heat input of 312,000 BTU/hr at 560°F inlet air temperature.

equation was developed showing the relationship between hot air to the dryer and the heat content (and therefore throughput) of the dryer. The basic relationship (6) is:

$$H = 0.24T + (1060.8 + 0.48T)\ Y$$

Where H = BTU/lb of dry air,

Y = lb water/lb dry air, and = 0.0173

T = Temperature $^{\circ}$F.

For average ambient conditions in Florida, the relationship is shown in Figure 13.

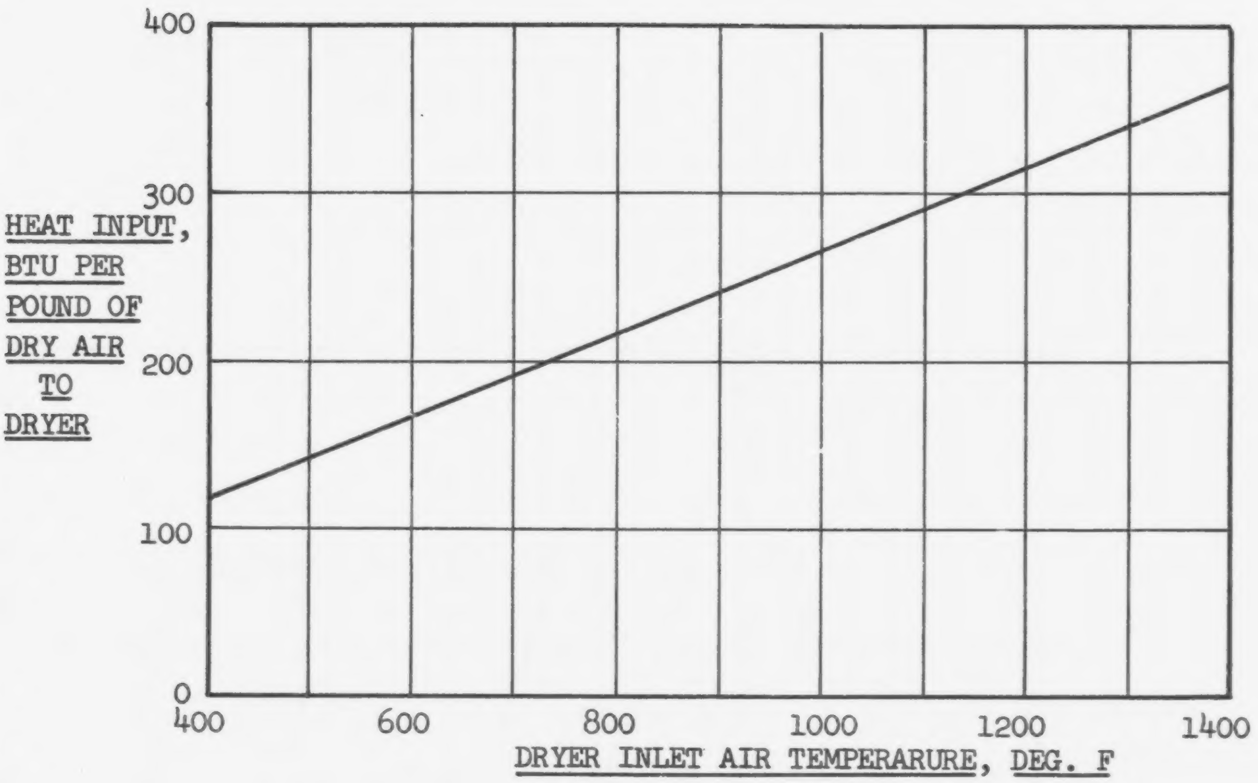


FIGURE 13. EFFECT OF AIR TEMPERATURE ON DRYER HEAT REQUIREMENT.

Estimated for ambient summer conditions in Florida.

The tests above have also shown that the recycle ratio, (see Glossary) has a strong influence on the performance of the system. Figure 14 shows that increasing recycle ratios tend to reduce the amount of water in the dryer feed, and therefore increase the potential capacity of the dryer. On the other hand, this figure also shows that increasing moisture content in the recycle stream increases the amount of water in the dryer feed and therefore tends to reduce its efficiency. Appendix B shows a typical calculation of the recycle ratio and its effect on the system operation. Most of the pilot tests on this dryer were carried out with recycle ratios in the range of 7 to 10, wherein the blender discharge moisture content was between 12 and 14%. Normally this would be considered excessive in terms of equipment size, power requirements, and heat loss. If it were possible to operate with a more efficient blender which would produce a discharge

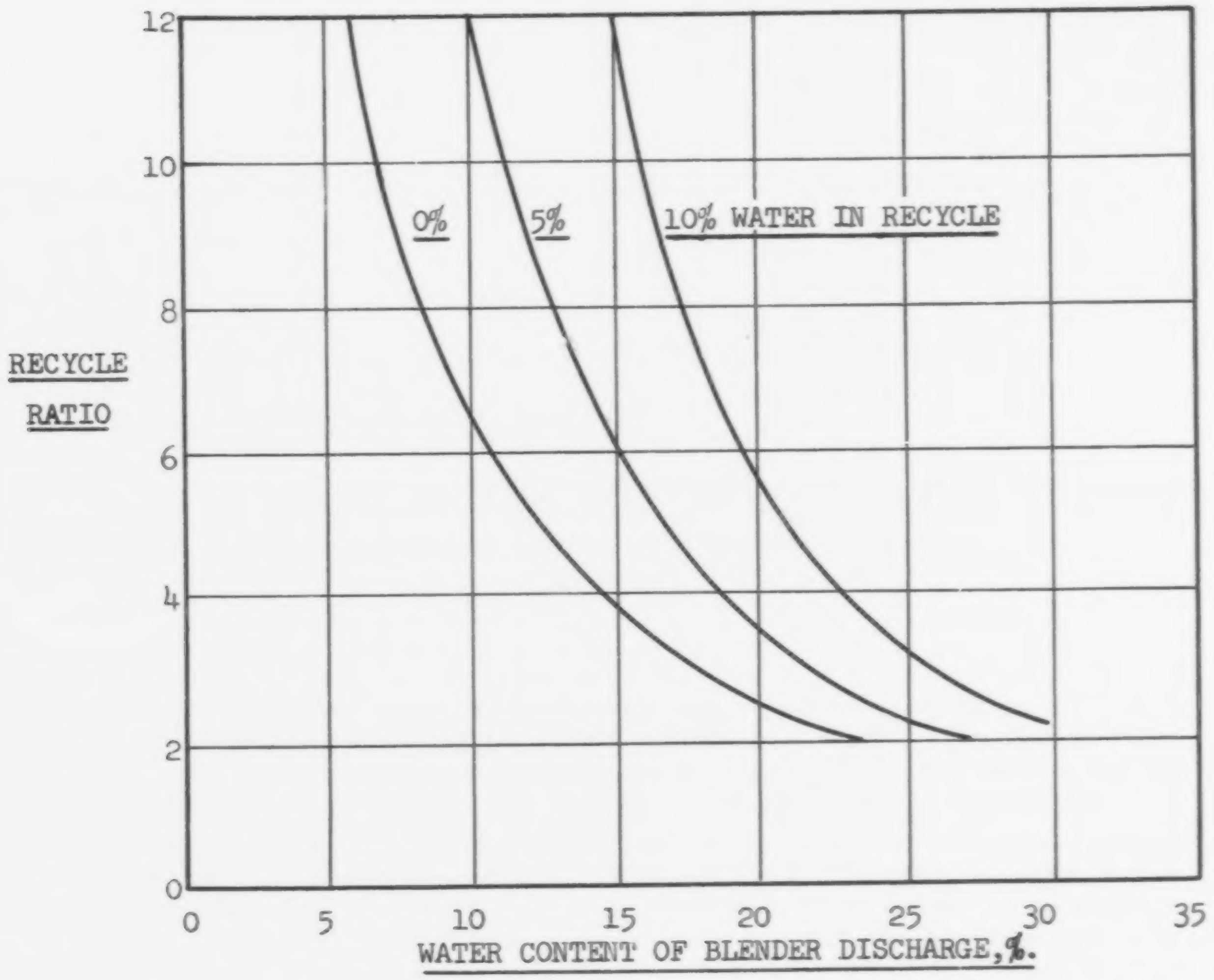


FIGURE 14. EFFECT OF MOISTURE ON RECYCLE RATIO TO FLUID-BED DRYER.
Recycle Ratio is pounds of dry product recycled per pound of fresh wet feed.

material in the range of 20 to 25% moisture, it is apparent from Appendix B that the recycle ratio would be cut in half. The essential effect of this would be to increase the overall capacity of the unit, and reduce its costs.

From the above evaluation of the fluid-bed dryer, estimates were made of the potential operating costs for a commercial sized unit, as shown in Table XII. It is estimated therein that for drying 100,000 tons per year of slimes-solids, starting with 30% material, it is reasonable to assume the net operating cost of $5.50 per ton of dried slimes-solids.

TABLE XII

ESTIMATED COST OF DRYING IN FLUID-BED DRYER

Basis: 30% slime-solids to dry slime at a rate of 100,000 TPY

	Cost per ton
Cost of slimes into dryer	$0.50
Fuel	2.50
Power	.50
Depreciation	1.25
Labor and Maintenance	1.00
	$5.75
Credit for ponding	.25
Cost per ton dry slime-solids =	$5.50

In order to verify these experimental results, independent calculations were made by Professor D. T. Wasan of Illinois Institute of Technology, as shown in Appendix C. In this study, Dr. Wasan derived a mathematical model, based on constant-rate drying, which was successful in predicting experimental values of final moisture content from the dryer. Data abstracted from Dr. Wasan's report as shown in Table XIII, indicate that the controlling mechanism in the dryer was heat transfer.

TABLE XIII

ANALYSIS OF DRYING EXPERIMENTS

Run No.	H_2O Balance Min.Air Rqd. # feed # air # feed	Min.Fluid Air # feed # air # feed	Air Needed for Heat # air # feed	Actual Air Used # air # feed
2	9.46	4.80	11.9	8.70
3	2.00	3.78	9.2	4.31
4	15.50	2.93	10.1	6.22
5	4.65	3.19	11.1	5.50

In the above Table, the underlined rate indicates the controlling rate that is limiting on each run. In all the runs (except Run 4), Heat Transfer was shown to be the controlling rate.

Kilning

Slimes products from IMC drying tests were processed through a pilot plant rotary kiln which was chosen because (1) the temperature can be accurately controlled, (2) it produces a round shape, minimizing sticking, (3) it is convenient to operate, (4) it produces a better grade of concrete, (5) raw materials that show satisfactory processing characteristics in the pilot plant unit, can generally be handled in a commercial kiln.

The kilning operation was aimed chiefly at producing products for evaluation rather than to produce design data for equipment. Evaluation of the equipment is a natural part of the Demonstration Project which should follow this report. Evaluation of the product is covered in the following sections of this report.

LIGHTWEIGHT AGGREGATE PRODUCT

During the course of this project, two types of aggregate were prepared. Initially, a somewhat angular material was produced from air-dried and crushed raw slimes and from fluid-bed-dried materials fired in a rotary kiln. The second type of aggregate was a rounded type produced by firing pelletized dried slimes.

Angular experimental lightweight aggregate was produced in trial quantities by firing dried, crushed and screened slimes in a rotary kiln at about 1050°C. Also, a +½ inch fraction of fluid-bed dried material was fired in a similar manner. Typical chemical analyses of these materials are shown in Table XIV and the physical properties in Table XV. In firing these materials, there was some difficulty with adherence of the fragments to each other and to the wall of the kiln, and crush strength was inadequate.

Slimes which had been dried in the fluid-bed dryer and agglomerated in a disc-agglomerator prior to kilning were also characterized. Table XVI shows the densities and porosities of these materials, and Table XVII the crush strength. For material having densities of 20 to 50 pounds per cubic foot, crush strength ranged between 634 and 2748 pounds per square inch, comparing very favorably with the crush strength of competitive materials. These data, however, showed that the material thus produced was considerably lighter (20-50 pounds per cubic foot) than conventional lightweight aggregate for structural concrete, (usually in the range of 40-60 pounds per cubic foot) yet maintaining satisfactory strength.

For ASTM tests (Specification Designation C330) these aggregates were blended to provide a coarse aggregate as shown in Table XVIII. The steam test for iron oxide revealed little staining, indicating the material is satisfactory for use in concrete and organic material was found either by chemical analyses or by soaking in caustic soda. No friable particles (i.e. crushable with the fingers) or lumps were found. The fineness modulous (FM - See Glossary) for these materials was found to be 5.6, whereas the modulous less than 4 characterizes fine aggregates and coarse aggregates may extend to about 7. This test, which indicates the average surface area of

TABLE XIV

CHEMICAL ANALYSES OF FIRED PHOSPHATE SLIME BODIES

	Pellets(1)	Brick Core (2)		5A (4)	IMD-5 (5)
		With Quartz Grog	Without Grog (3)		
SiO_2	38.0%	56.0%	41.2%	39.5%	39.0%
Al_2O_3	17.6	13.9	18.9	18.0	17.8
CaO	18.1	13.3	18.1	18.4	18.4
P_2O_5	13.4	10.1	13.7	13.4	14.0
MgO	3.08	1.64	2.23	3.20	3.08
Fe_2O_3	5.56	3.51	4.77	5.13	5.15
MnO	.04	.03	0.04	.03	.03
TiO_2	.62	.49	0.67	.62	.61
Na_2O	1.14	0.77	1.05	0.67	0.18
K_2O	0.78	0.34	0.46	0.76	0.75
C	0.05	0.00	0.00	0.03	0.07
CO_2	0.22	0.00	0.00	0.30	0.24
H_2O^-	0.05	0.03	0.03	0.04	0.03
H_2O^+	0.01	0.01	0.01	0.00	0.07
SO_3	0.18	0.04	0.05	0.21	0.18
F	1.33	1.03	1.40	1.56	1.38

(1) Air-Dried Slime 1A
(2) Fluid-bed Dried Slime IMD-3
(3) Calculated
(4) Air-Dried Slime 5A
(5) Fluid-bed Dried Slime, IMD-5

TABLE XV

PROPERTIES OF ROTARY KILN FIRED AND CRUSHED PHOSPHATE SLIME LIGHTWEIGHT AGGREGATE(1)

U.S.Screen Size(2)		Wt%	Cumulative Wt%	Unit Wt lb/ft	Crushing Strength				
					1 in.	1½ in.	2 in.	2½ in.	3 in.
1) 5A*									
a) +1/2 in. kiln feed:(3)									
-1	+1/2	58.5	58.5	13.54	41	69	110	184	298
-1/2	+3/8	18.2	76.7	13.28	37	73	138	243	422
-3/8	+4	15.0	91.7	19.85	96	193	330	665	1147
-4		8.3	100.0	23.46	83	170	229	642	1083
b) -1/2 in. kiln feed:									
-1	+1/2	23.5	23.5	11.50	41	78	124	225	431
-1/2	+3/8	18.2	41.7	14.51	78	147	262	486	1165
-3/8	+4	46.2	87.9	17.10	73	142	234	431	734
-4		12.1	100.0	24.94	73	165	303	596	1101
2) IMD-5* (+1/4 in. kiln feed)(4):									
-1	+1/2	32.2	32.2	12.01(5)	37	78	138	229	376
-1/2	+3/8	13.8	46.0	13.64	37	73	133	248	413
-3/8	+4	34.8	80.8	16.44	39	128	220	440	734
-4		19.2	100.0	23.82	119	220	399	729	1330
3) IMD-3* (+1/4 in. kiln feed)(4):									
-1	+1/2	59.7	59.7	18.85(5)	92	147	238	468	853
-1/2	+3/8	11.5	71.2	19.55	87	147	243	463	771
-3/8	+4	13.4	84.6	22.80	119	202	312	546	954
-4		15.4	100.0	39.09	128	339	734	1743	3762

(1) Nos. 1 and 2 fired to 1050°C; No. 3 fired to 1150°C (over-fired). (2) above line = kiln feed; below line = product. (3) air-dried. (4) fluid-bed dried. (5) inaccurate because of small amounts available. *Code identification shown in footnotes to Table XIV.

TABLE XVI

DENSITY AND POROSITY OF EXPANDED PHOSPHATE SLIME AGGREGATES (1) (2)

U.S. Screen Size	True specific gravity (3)	Apparent specific gravity	Bulk Density	Apparent Porosity, %	Sealed Porosity, % (4)	Volume % of Solids (5)	Measured Unit Weight, lb/ft^3
1) **IMD-3**							
+1/2	2.6	1.58	0.81	49.0	19.8	31.2	20.44 (6)
-1/2+3/8	2.6	1.40	0.69	50.7	22.8	26.5	26.97
-3/8+4	2.6	1.64	0.79	51.8	17.8	30.4	30.31
-4+8	2.6	1.71	0.80	51.3	17.9	30.8	32.52
-8	2.6	1.45	0.65	55.0	20.0	25.0	50.54 (6)
2) **IMD-4**							
+1/2	2.6	1.67	0.78	53.2	16.8	30.0	19.65 (6)
-1/2+3/8	2.6	1.54	0.66	57.3	17.3	25.4	21.68
-3/8+4	2.6	1.49	0.74	50.0	21.5	28.5	25.10
-4+8	2.6	1.47	0.78	47.3	22.7	30.0	27.28
-8	2.6	1.49	0.62	58.1	18.0	23.9	40.31 (6)

IMD-3 and IMD-4 -- Fluid-Bed Dried Slimes

(1) firing range 1100-1150°C
(2) pelletized in rotating inclined disc
(3) approximation
(4) based on estimated true specific gravity
(5) based on estimated true specific gravity
(6) insufficient material for accurate measurement

TABLE XVII

PROPERTIES OF ROTARY KILN FIRED EXPANDED PHOSPHATE SLIME AGGREGATES (1)(2)

U.S. Screen Size	wt%	Cumulative wt%	Unit wt. lb/ft^3	Crushing Strength,psi 1 in.	$1\frac{1}{2}$ in.	2 in.	$2\frac{1}{2}$ in.	3 in.
IMD-3								
+1/2	5.96	5.96	20.44		insufficient quantities			
-1/2+3/8	6.24	12.20	26.97	211	391	740	1311	2167
-3/8+4	56.90	69.10	31.30	423	645	1078	2125	--
-4+8	23.30	92.40	32.52	634	1015	1797	3700	--
-8	7.59	99.99	50.54		insufficient quantities			
IMD-4								
+1/2	17.01	17.01	19.65		insufficient quantities			
-1/2+3/8	21.32	38.33	21.68	222	370	634	1226	--
-3/8+4	37.46	75.79	25.10	529	899	1691	--	--
-4+8	14.71	90.50	27.28	825	1480	2748	6131	--
-8	9.50	100.00	40.31		insufficient quantities			

(1) firing range 1100-1150°C

(2) pelletized in rotating inclined disc

the aggregate indicates that this material should result in workable concrete mix. These tests are summarized in Table XIX which shows that these materials satisfy the requirements of ASTM C330.

TABLE XVIII

PROPERTIES OF BLENDED (1) COARSE PHOSPHATE SLIME LIGHTWEIGHT AGGREGATE

U.S. Screen Size	Wt%	Cum.Wt %	% Through Sieve (2)	ASTM (3)
-1/2 +3/8	5.15	5.15	100	100
-3/8 +4	54.24	59.39	94.85	80-100
-4 +8	37.63	97.02	40.61	5-40
-8 +16	2.94	99.96	2.99	0-20
-16 +30	0.02	99.98	--	--
-30 +50	0.01	99.99	--	--
-50 +100	0.02	100.01	--	--
		561.50∴FM=5.62 (4)		

Blended Unit Weight is 27.92 lb/ft^3

(1) IMD-3 and IMD-4

(2) Wt% passing through larger sieve indicated.

(3) ASTM C330, wt% passing through larger sieve for ½ in. to #4 aggregate.

(4) Fineness Modulus.

Fired pellets had a specific heat of 0.24 BTU/lb/^{O}F, compared with commercial lightweight aggregate (Materialite) which has a specific heat of 0.25 BTU/lb/^{O}F. It was determined by mercury porosimetry that the apparent density (See Glossary) of these materials is 103 pounds/cubic foot, and that the theoretical density of the basic material (See Glossary) is 155 pounds/cubic foot.

Fired slime aggregates were also characterized according to ASTM C127 (Specific Gravity in Absorption of Coarse Aggregate), and ASTM C88 (Soundness of Aggregate by the use of Sodium Sulfate or Magnesium Sulfate) as shown in Table XIX. Water absorption for the slimes lightweight aggregate is about 30%, while that for LWA made from clay or slate processed in a rotary kiln is in the vicinity of 20 to 25% absorption of water. Most normal weight

TABLE XIX

SPECIFICATIONS OF PHOSPHATE SLIME LIGHTWEIGHT AGGREGATE ACCORDING TO ASTM C330 (LIGHTWEIGHT AGGREGATES FOR STRUCTURAL CONCRETE)

Test	Method	Results
Staining	ASTM C330	Stain intensity is light to very light; Stain Index = 40 to 20
Loss on Ignition	ASTM C114	Chemical analysis indicates <0.6% volatiles
Organic Impurities	ASTM C40	No apparent organic materials
Grading	ASTM 136 & ASTM C330	Not graded according to specifications (1)
Friable Particles in Aggregates	ASTM C142	0% friable
Clay Lumps	ASTM C330	None discernible
Fineness	ASTM C142	5.62 (coarse aggregate) (2)
Unit Weight	ASTM C29	27.92 lb/ft^3 (average) (3)
Bulk Specific Gravity	ASTM C127	0.845
Bulk Specific Gravity (Saturated Surface-Dry Basis)	ASTM C127	1.12
Apparent Specific Gravity	ASTM C127	1.16
Water Absorption	ASTM C127	32.2%
Soundness (Sodium Sulfate)	ASTM C88	~4.8% size reduction

(1) Quantities produced required economical use of all available aggregates, thus providing a somewhat non-specific material.

(2) For information only, more applicable to fine aggregate.

(3) Conforms to specifications (dry-loose basis). Maximum allowable unit weights range from 55 to 70 lb/ft^3, depending on size of aggregate.

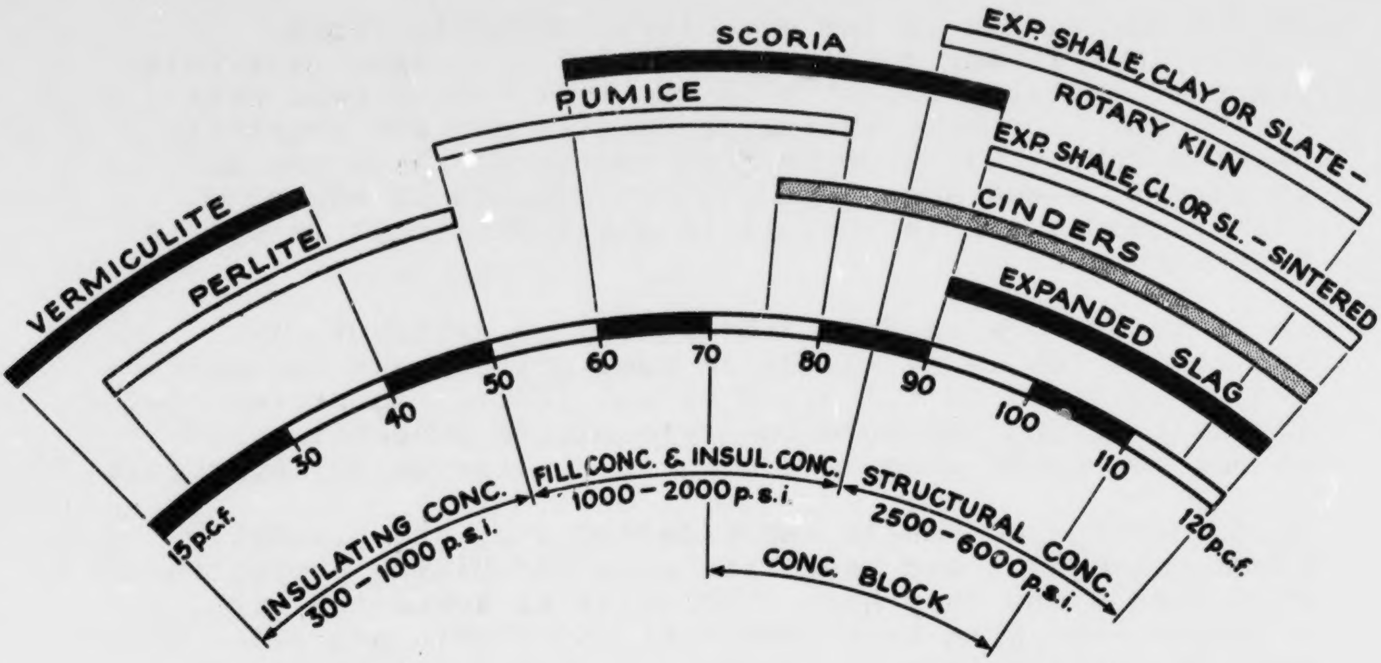
aggregates, such as granite, dolomite, quartzite and schist absorb less than 2% water. Although the larger sized aggregate ($-\frac{1}{2}$ +3/8 in.) deteriorated in the saturated sodium sulfate solution test after 20 cycles, the smaller size (-3/8 +8 mesh) showed no measurable deterioration.

Starting with 30% slimes-solids and based on estimated cost of $4.50 per ton of dry slimes-solids (as per Table XII), production cost of lightweight aggregate is estimated to be of the order of $8.00 to $9.00 per ton. This works out to be about $3.00 per cubic yard of this type of product (about 675 lbs/cubic yard). In comparison, a variety of LWA is sold in Florida at about $4.50/cubic yard (1300 lbs/cubic yard) or about $7.00 per ton. Since there are no competitive producers of LWA (for structural concrete) in the immediate area, as shown in Appendix E, LWA from slimes has a good potential market within easy access to Tampa and Ocala areas.

A study of the transporation of light aggregates produced from clay slimes was made as shown in Appendix D. This indicates that the economic location for producing dried slimes is at the slimes pond site. If the average density of the product mix is light (less than 28 lbs/cubic foot) and large hopper cars are available, it would be most economical to fire the slimes at a point near Bartow, Florida, and ship the lightweight aggregate to the Tampa, Miami, and Jacksonville areas. If large cars are not available, it would be economical to establish sattelite kiln operations at Miami and/or Jacksonville. If the product mix had an average density greater than 28 lbs/cubic foot, the study shows that it will always be cheaper to produce fired lightweight aggregate in the Bartow area.

The final stage of the present project was preparation of trial lots of lightweight concrete from phosphate slimes expanded aggregate. Production of both insulating and structural concretes were investigated and consideration was given to the possibility of making concrete blocks. The inter-relationship of these types of building materials is shown in Figure 15, as developed by the Portland Cement Association (8). Structural lightweight concrete is defined as that which: (1) is made with lightweight aggregate and conforms to ASTM C330, (2) has a compressive strength in excess of 2500 lbs/sq. foot at 28 days when tested according to ASTM C330, (3) has an air-dry weight not exceeding 115 lbs/cubic foot as determined by ASTM C567. Concrete in which a portion of LWA is replaced by normal weight aggregate (e.g. sand) and which meets the strength and weight limitations is within the scope of ASTM C330. Since phosphate slime LWA falls within the specifications as outlined, use of structural lightweight concrete is desirable and was tested accordingly.

FIGURE 15. SPECTRUM OF LIGHTWEIGHT CONCRETES



At the low end of the scale we have the "super" lightweight aggregates, vermiculite and perlite. They are capable of producing a highly insulative concrete but with compressive strengths ranging from 200 or 300 psi to a maximum of 1000 psi. This concrete is used as an insulative roof fill over a structural system or as fireproofing and is generally applied by licensed applicators or subcontractors. The aggregate also finds widespread use in making lightweight plaster.

At the high end of the scale we have structural concrete ranging in unit weight from 85 to 120 pcf and capable of developing compressive strengths from 2500 psi to 5000 and 6000 psi and even more. Note that all of the materials shown here are not necessarily able to produce the high strength concretes.

Between the two extremes, with strengths from 1000 to 2000 psi and unit weights between 50 and 85 pcf, are fill concretes, that have some insulative value some inherent strength. Depending on the materials and the techniques of using them these concretes may have properties of finishability or wearability and at the high end of their range may be used in making small precast products.

Concrete used in making lightweight concrete block falls in the range of weight from 70 pcf to 110 pcf and includes all of the materials shown except the "super" lightweight aggregates.

FIGURE 15. SPECTRUM OF LIGHTWEIGHT CONCRETES (Cont.)

Of the aggregates in the structural concrete range, pumice, scoria and tuff are natural lightweight materials, found in volcanic deposits in the West. They have generally poor concrete making properties and are primarily used in making block or in fill concrete. With the use of natural sands some deposits are capable of making a fairly good concrete, but it is still difficult to obtain high strengths.

Coal cinders are rapidly diminishing in availability and that which is available is used principally in concrete block and to a limited extent in fill concrete. It has poor and variable concrete making properties and is not currently used as a structural lightweight aggregate.

Sintered expanded shale and expanded slag are primarily block aggregates and have fair concrete making properties. When used alone they have difficulty in achieving high strength even with high cement factors; with natural sand the unit weights tend to be high but the concrete is quite satisfactory in other respects. Of the two, the sintered expanded shales are used to a larger extent in structural applications.

The rotary kiln expanded shales have good to excellent concrete making properties and achieve high strength with reasonable cement factors. In addition they have all of the other desirable properties of quality concrete. It is the principal aggregate used today in making structural lightweight concrete with about 75 to 85% of all structural lightweight concrete using this aggregate. It is also used in making quality lightweight concrete block.

All of these structural aggregates with increased air contents are capable of producing fill concrete at lower unit weight and with a corresponding reduction in strength. Of course the spectrum becomes quite confused when materials are blended with each other (rarely done) or when mixed with natural sand (frequently done) or when the air contents vary from low to excessive.

Trial batches were prepared according to ACI 211.2-69 (Recommended Practice for Selecting Proportions for Structural Lightweight Concrete) (9). Table XX shows the proportions used in the concrete test trials and lists the properties of the concretes produced in the plastic state.

High-early-strength (Type III) cement was initially used to expedite testing of hardened concrete. This type of cement obtains almost the same strength in 7 days as normal cement obtains in 28 days. Results obtained on mixtures so made are shown in Table XXI, which indicates that such a mixture compares quite favorably with ASTM Specification C330. This table also shows that a 3½ bag per cubic yard mix (87 lbs/cubic foot) was not satisfactory. This latter material had been made using the initial angular aggregates which accounts for its unsatisfactory performance. A third and lighter weight batch was prepared as shown in Table XX. The properties of this concrete compare very favorably with ASTM standards. Table XXII shows the size distribution of the fine aggregate used in this mix. The data of these three tests and the appropriate ASTM Specifications are displayed in Figure 16. In addition, a method was developed, as shown in Appendix F, of estimating concrete strength from aggregate crush strength results. The results of the 5th and 6th trial batches are shown also in Table XX and data for these five trials are shown in comparison in Table XXI.

A batch of lightweight concrete was made in the 50 lb/cubic foot range to determine if insulating concrete can be made. Figures 17 and 18 show the inter-relationship of thermal conductivity, density and compressive strength of lightweight concrete after 28 days. It was noted while preparing this mixture that the texture was quite harsh and excess fines and water were added to produce a workable mix. These adjustments, however, increased the water to cement ratio to 1.49 causing excessive bleeding, segregation of aggregate and cement slurry, and low strength (average 238 psi at 28 days). Although this was by no means satisfactory, it gives encouragement for further tests with the possibility that proper adjustment of the mix will raise the strength of the material as contemplated.

TABLE XX
PREPARATION AND PROPERTIES OF PLASTIC EXPANSIVE CONCRETES USING PHOSPHATE SLIME COARSE LIGHTWEIGHT AGGREGATE

	TRIAL BATCH NUMBER							
Concrete Mix Proportions	1	3	5	6	7	8	9	10
Cement (Atlas), Type	III	III	I	I	I	I	I	I
Cement (Atlas), bags (94 lb/bag)	5	5.5	5	6	11.4	6	11.4	6
Cement (Atlas), lb/cu.yd.	470	517	470	564	1069	564	1069	564
(incl. mortar mix, lb/cu.yd.					(54)		(54)	
Coarse Aggregate, Phosphate Slimes lb/cu.yd.	448	496	356	356	240	356	240	356
Fine Aggregate, lb/cu.yd.	1560	880	1560	1560	1053	1560	1053	1560
Tap Water, room temp., lb/cu.yd.					(5.4)	(3.0)	(86.4)	(48)
(incl. IMC additives, fl.oz/cu.yd.	450	421	454	513	451	427	459	481
Design total, lb/cu.yd.	2928	2314	2480	2993	2813	2907	2822	2961

Plastic Concrete Properties (Before Significant Expansion)								
Slump (ASTM C143) inches	2.75	3.0	2.75	3.0	5.5	3.75	5.25	7.5
Unit Wt. (ASTM C138) lb/cu.ft.	111.9	93.88	103.4	106.2	113.8	106.8	103.3	104.0
Vol. Conc.Prod. (ASTM C138)cu.ft.	26.17	24.65	27.47	28.18	24.73	27.22	27.24	28.47
Yield (ASTM C138) cu.ft. concrete/bag cement	5.23	4.48	5.49	4.70	2.29	4.54	2.52	4.74
Relative Yeild (ASTM C138)	0.969	0.913	1.02	1.04	0.916	1.01	1.01	1.05
Bags cement/cu.yd. conc. prod.								
"Actual" Cement Factor (ASTM C138)	5.16	6.03	4.91	5.75	11.79	5.95	10.70	5.7
Air Content (ASTM C173) %							4.0	5.5

TABLE XXI

AVERAGE COMPRESSIVE STRENGTH OF 3 x 6-in. LIGHTWEIGHT CONCRETE CYLINDERS USING FIRED PHOSPHATE SLIME AS COARSE AGGREGATE (1) (2)

Mix(bags/yd^3)	Unit Weight (lb/ft^3)	Time of Cure (Days)				
		1	3	7	10	28
5	109	689(3)	1741	2107	2681	2933
3-1/2	87	--	--	--	--	1158
ASTM Specifications C330 (Lightweight Aggregates for Structural Concrete)						
	105	--	--	--	--	2000(4)
	110	--	--	--	--	3000
	115	--	--	--	--	4000

---

(1) Compared to concrete previously produced (Quarterly Report No. 3) and ASTM C330

(2) This study compares Type III Cement with Type I Cement used previously. Thus compressive strength of concrete with Type III cement at 7 days is about equivalent to concrete with Type I cement at 28 days.

(3) lb/in^2

(4) Average 28 days compressive strength, min. psi.

TABLE XXII

GRAIN SIZE DISTRIBUTION OF FINE AGGREGATE (MATERIALITE) USED IN THIRD CONCRETE BATCH

U.S. Screen Size	ASTM C33 % Through	% on (1) (2) Screen	Cumulative % on Screen
3/8	100	0	0
4	95-100	2	2
8	80-100	6	8
16	50-85	19	27
30	25-60	30	57
50	10-30	25	82
100	2-10	14	96
pan	--	4	100

(1) Custom blended to conform to ASTM C33

(2) Fineness Modulus = 2.72

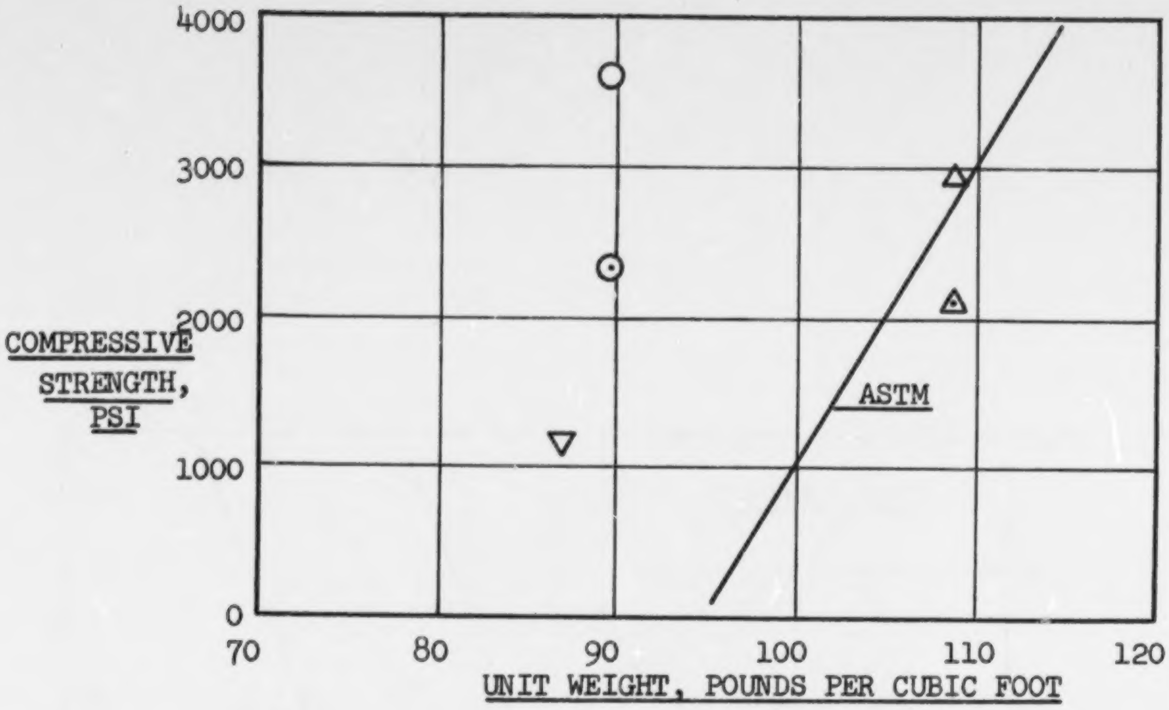


FIGURE 16. COMPRESSIVE STRENGTH OF CONCRETE MADE WITH PHOSPHATE SLIME COARSE AGGREGATE.

Symbol:	7 day	28 day	Fine Aggregate	Cement Factor
		▽	Sand	3½
	◬	△	Sand	5
	⊙	○	Materialite	6

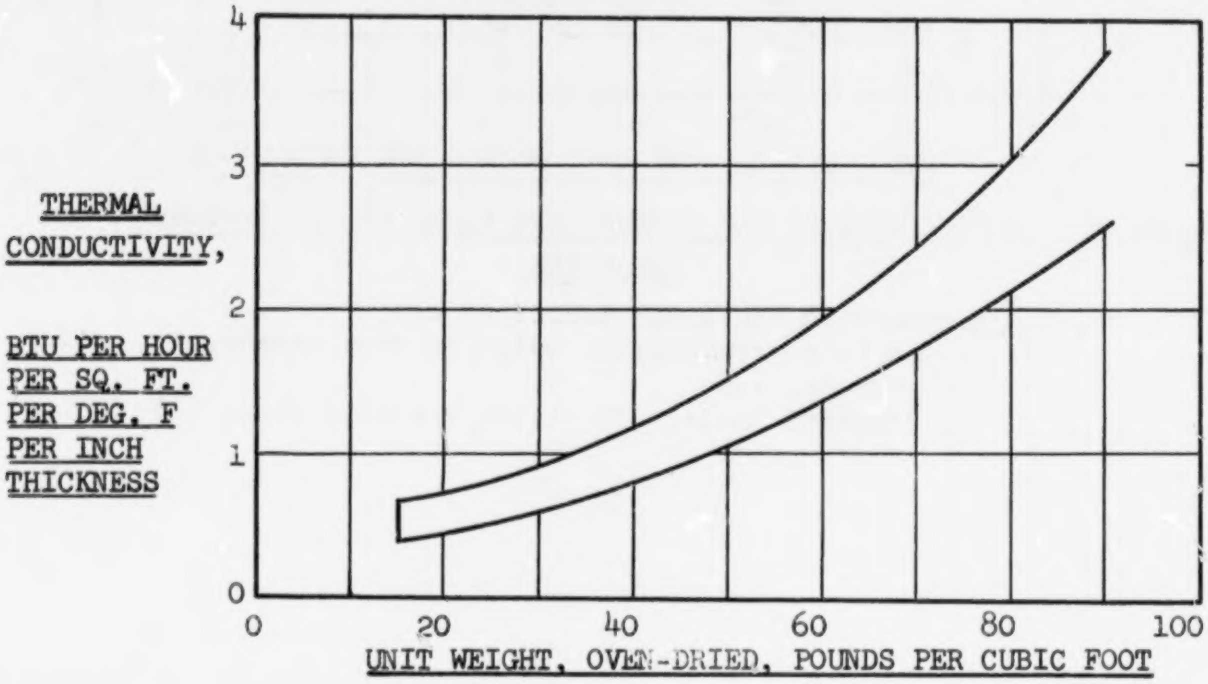


FIGURE 17. APPROXIMATE THERMAL CONDUCTIVITY OF INSULATING CONCRETE.

Thermal conductivity of normal concrete generally ranges from 9.0 to 12.0.

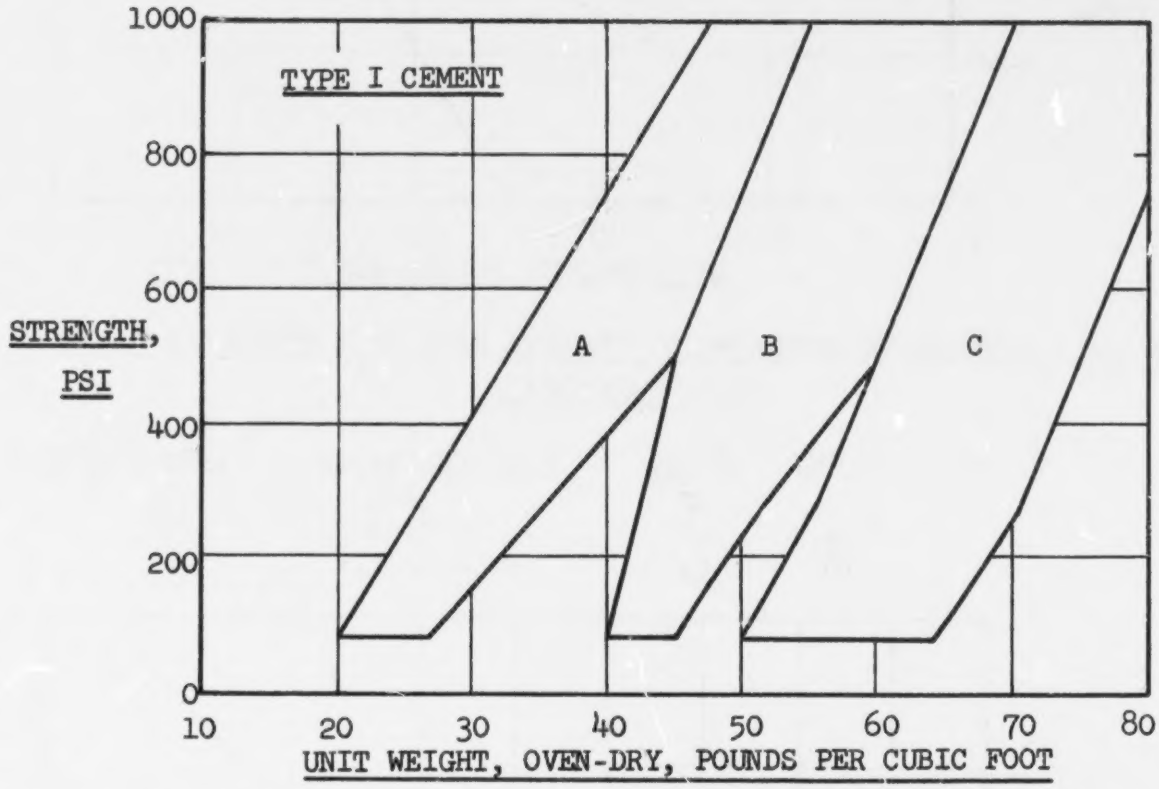


FIGURE 18. APPROXIMATE 28-DAY COMPRESSIVE STRENGTHS OF INSULATING CONCRETES.

Aggregates in the areas indicated are;

A...perlite,vermiculite, cellular neat cement, 1:3 -1:10
B...pumice, 1:5
C...expanded shale, 1:5 -1:14; expanded slag, 1:5 -1:9.

Preliminary data showed that both concretes displayed relatively high compressive strengths with somewhat lowered water requirements. When compared to the strength-density requirements of ASTM C330, indications are that both concretes will conform to these specifications. The data indicate that the admixture used is not detrimental to the strength of the concrete as designed and, in fact, appears to increase the strength. Moreover the use of foam presents about 20% savings in weight over the lightweight concrete normally produced in this study.

SUMMARY

The objective of this project was to develop a means of disposing economically of a significant portion of the enormous volume of aqueous slimes generated as waste from the Florida phosphate mining industry. To that end, a potentially economical method of producing fired lightweight aggregate for lightweight concrete has been developed on a scale sufficient to show that the data are reliable. In addition a drying process, more economical than those previously studied, has been developed which not only is suitable for lightweight aggregate preparation but should reduce the cost of producing other materials from slimes. The possibility of producing other structural shapes in ceramic materials including tile, pipe, and brick, was also investigated.

Emphasis was placed on the development of lightweight aggregate as the key product of this project since this was the largest volume product of those considered and had the greatest possibility of rapid and economical reduction to practice. The project has, at this time, been carried to the point of having demonstrated each piece of equipment (or unit-operation) on a small scale (at the Erie Pilot Plant as part of this project) and having produced reasonable quantities of dried-slimes, fired-aggregate and concrete test-blocks to assure that the data so far obtained -- which are encouraging -- are valid. The lightweight aggregate produced from slimes passed all the ASTM specifications (Lightweight Aggregates for Structural Concrete - ASTM C330). The next step in pursuing utilization of the results of this report will be to produce on semi-works or demonstration plant scale, sufficient product material from pond-slimes in a continuous manner and in sequential steps to verify the encouraging economics developed herein. In addition to and concurrent with such a study, further work should be done to evaluate the potential of using these slimes in producing other ceramic products.

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GLOSSARY

ACI - American Concrete Institute.

Apparent porosity - the volume of open pore space in a material per unit total volume.

Apparent specific gravity - the ratio of weight in air of a unit volume of material to the weight in air of equal density of an equal volume of gas-free distilled water. In this study, the volume is that portion impermeable to boiling water.

ASTM - American Society of Testing Materials.

Bloating - excessive expansion of a ceramic body upon heating, characterized by alteration of dimensions and dimensional ratios. Sometimes accompanied by splitting and tearing at the surface.

BPL - Bone phosphate of lime.

Core - formation in the center of a ceramic body characterized by discoloration, separation from the outer layer (lamination) and general weakness of the body. Caused by imperfect shaping procedures, poor composition, or irregular firing.

Density - Theoretical - wt of particle/(vol of particle - vol internal voids)
Apparent — wt of particle/ (vol of particle)
Bulk - gross wt of solids/gross volume

Differential thermal analysis (DTA) - measurement of gain or loss in energy for a material, during controlled change in temperature, as a result of vitrification, vaporization, phase transitions, adsorption or desorption of gases, loss of water (usually in several steps), decomposition, chemical reaction, oxidation or reduction.

Dilatent - fluids have apparent viscosity, increase with increasing shear rate.

Draw trial - a heating and firing test in which, at specific temperatures, i.e. 100 or 50°C intervals, or at temperature holds, a number of ceramic pieces are withdrawn from the kiln and examined to detect and measure the effects of heat and time on certain properties, such as shrinkage, weight loss, density, porosity, warpage, etc.

Drying Efficiency - Herein the drying efficiency is defined as:

$$\frac{H_1 + H_2 + H_3 \times 100}{\text{Total BTU Input}}$$

Where: H_1 = Heat req'd to heat up dry solids from ambient to discharge conditions.

H_2 = Heat req'd to heat up water content of solids from ambient to discharge conditions.

H_3 = Heat req'd to evaporate water content into stream.

Throughput is defined as pounds per hour of wet feed to the dryer.

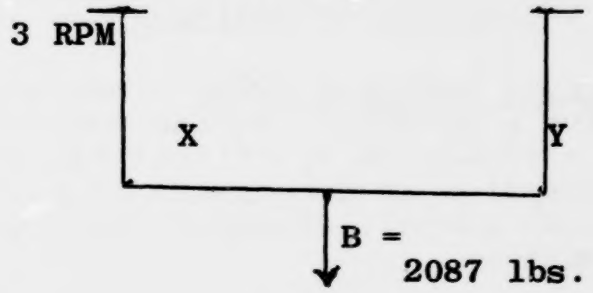
Dust Loading - Typical Calculation of Dust Loading on Bag Dust Collector

Assume: Moisture content of dryer discharge is the same as dryer overhead to Dust Collector.

Given: From previous calculation B - 2087 lbs.
Star Valve discharges $0.15\ \frac{\text{cu.ft}}{\text{rev.}}$

Density dry product - 64 lbs/ft^3

Then: From Dryer Discharge — From Dust Collector



Expansion - increase in size of a ceramic body while retaining general shape and dimensional ratios.

Fineness module (FM) - is an index of the coarseness or fineness of a material, and is essentially 1/100 of the summation of weights of aggregate retained on each of a specified series of sieves.

Green - wet-formed and weak, not hardened or fused.

Grog - a granular material generally produced from calcined or fired refractories, added to a ceramic composition for the purpose of reducing shrinkage, weight loss, and for increasing strength.

Hydrophyllic - describes a substance which attracts water or to which water adheres.

IITRI - Illinois Institute of Technology Research Institute.

LWA - Lightweight aggregate.

Materialite - produced by Material Service Corporation.

Nitrin — a joint venture of IMC and Northern Natural Gas, at Cordova, Illinois, now shutdown.

PCE - pyrometric cone equivalent (Cone Test) according to ASTM C24; measurement of the effect of time and temperature upon firing a ceramic. Also referred to but not synonymous with fusion point, deformation point, and melting point.

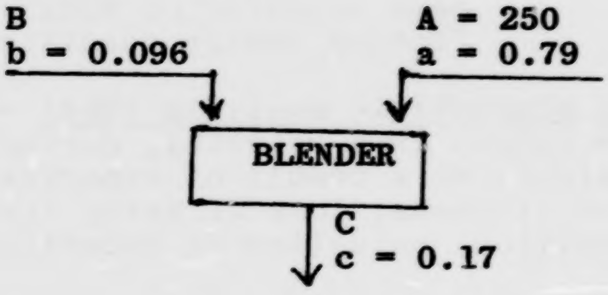
Plastic - Bingham plastic fluids require a finite shear stress to initiate flow.

Quench - (1) to lower the temperature, generally quite suddenly, of ceramic ware, or (2) to extinguish a flame.

Recycle Ratio - Typical Calculation of Recycle Ratio for 2 sq. ft. Cross-Flow Dryer.

Assume: Moisture content of dryer discharge is the same as dryer overhead product to Dust Collector.

Then: Moisture in Blender Discharge = 17% H_2O
Star Valve delivers 0.15 cu.ft/rev.
Feed Rate - 249 lbs/hr.
Feed Moisture - 79%



Recycle Ratio - Continued

Overall material balance around blender

$A + B = C$

Where: A = Wt. of Feed
B = Wt. of Recycle
C = Wt. of A & B

Moisture Balance

$A(a) + B(b) = C(c)$

Where: a = Fraction H_2O in A
b = Fraction H_2O in B
c = Fraction H_2O in C

$A = 250$ lbs.
$a = 0.79$
$b = 0.096$
$c = 0.17$

Rheology - science of the motion characteristics of fluids.

Thermal Efficiency - Herein thermal efficiency is defined as:

$$\frac{H_1 + H_2 + H_3 + H_4 \times 100}{\text{Total BTU Input}}$$

Where: H_1 = Heat req'd to heat up dry solids from ambient to discharge conditions.

H_2 = Heat req'd to heat up water content of solids from ambient to discharge conditions.

H_3 = Heat req'd to evaporate water content into stream.

H_4 = Heat req'd to heat up air necessary for mass transfer of water from slimes solids under Florida design conditions.

Thermal gravimetric analysis (TGA) - measurement of gain or loss in weight in a material, during controlled changes in temperature, as a result of vaporization, adsorption or desorption of gases, loss of water (usually in several steps) decomposition, oxidation or reduction.

Thixiotropic - fluids possess a structure which breaks down with both shear rate and time. As it breaks down with constant shear rate, shear stress decreases.

Ware - pertains to articles of the same class; especially, manufactured articles. In this instance, pertains to ceramic ware such as brick, pipe, tile, etc.

Water absorption - the relationship of the weight of water absorbed to the weight of the dry material.

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APPENDIX A

AN APPRAISAL TO MANAGEMENT OF THE PROJECT

By

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October 21st, 1970

Dr. Srini Vasan
International Minerals & Chemical Corporation
Administrative Center
Skokie, Illinois 60076

Products from Phosphate Slimes

Dear Mr. Vasan:

It was a very real pleasure to review with you so thoroughly this development under your direction at International Minerals & Chemical Corporation at Skokie and Libertyville, Illinois, and with the help of Illinois Institute of Technology Research Institute at Chicago.

The Problem and Its Background

The problem has been well defined and is well understood. It is the basis of the development contract of International Minerals and Chemical Corporation (IMC) for the handling of slimes produced in beneficiating of phosphate rock mined in the deposits near Bartow, Florida. These slimes are now stored for indefinite periods in ponds with banks made of dams which have to be artificially built up. The level of the impounded material stands much above the level of the surroundings. The dams which are built to enclose an area and form the ponds break sometimes; and the slimes released pollute considerable amounts of surface waters and large areas of farm lands before the flood can be controlled.

There is also a constant seepage from the ponds which may present a problem to fresh water aquifers. Moreover, this removal and storage above ground of considerable amounts of ground water causes a lowering of the water table; and in this low area only a few feet above tide water level, there is the very real danger of encroachment of sea water into the fresh water aquifers due to this displacement.

The first part of the problem is the development of satisfactory methods for dewatering the colloidal slimes; and some attention has been paid to this. However, while the solution of this problem has not been demonstrated on a major scale, it is believed by this writer that it is quite possible to decant satisfactorily by far the most of the water substantially free of solids in a relatively short space of minutes by the addition of very cheap coagulants.

Methods which would probably accomplish this separation and would thus free most of the water and thus most of the storage volume now taken up by the slimes have been described in U.S. Patents Nos. 3,338,828 and 3,388,828 to Joseph R. Clark. This system utilizes as a coagulant fly ash which is available from power stations at no cost but that of carrying it away. After a special treatment with acid, this fly ash, along with very minor amounts of polyelectrolytes should give a very prompt and substantial removal of most of the water to give a range of solids between 25 and 30%, which is otherwise attained in the storage ponds only after a period of years. It is probable that similar results might be obtained with other coagulation and sedimentation techniques, more or less standard to those who are familiar with the best practices in the treatment of sanitary and industrial wastes or sewages. Thus, this part of the problem is not regarded as of the most importance - at least from the standpoint of its difficulty of solution.

One of the important aspects of this problem is the increasing requirement of valuable land for utilization as slime ponds, since there is required for each 2 cubic feet of phosphate some 3 cubic feet of storage for slimes in water. Once the dams are built for making such storage, it is almost a complete condemnation of the land for all future time for the removal of the waste which stands there then for indefinite periods.

Alternatively, the removal of the slimes as fast as they are formed would save future encroachment of this land, which may be valued at probably $200 to $500 per acre (and it is becoming less and less available at any price). Some ponds which have been dried and dredged to give lagoons and clay lands for farm use give excellent crops and citrous orchards; others have been developed for residential developments with a very high selling price after the costs have been paid. The continuing pollution or waste of land could thus be stopped with development of methods of removing the water for reuse and for selling the solids. If it were possible to develop markets for more than the present production of solids in the slimes, there would then be at least several hundred million tons of solids available in present storage for use as raw materials and for sale, and with the accompanying freeing of valuable space and the removal of the water for reuse and ultimate transfer to the underground aquifer as part of the future water resources.

The background of the industry involves the handling of tremendous amounts of these slimes. IMC alone has to dispose of some 10 million tons per year of the slime solids in producing 8 million tons per year of phosphate rock, 30% of the industry total. However, IMC's annual capacity is larger, 12 million tons of phosphates; and IMC, like the rest of the industry, is operating at a lowered output. The cost to IMC of waste disposal by ponding is about 25¢ per ton of slime solids, which is about 32¢ per ton of phosphate rock produced, or $2.5 million per year on the present 8 million tons production.

One of the major problems of the phosphate rock industry is that it has a vastly greater capacity than can be utilized, with consequently considerable competition and a price which has reduced in the last 5 years from $6.00 per ton (f.o.b. mine) to $4.00 per ton in 1970. Another point is that, from the standpoint of destruction of land values and potential pollution of water, it is distinctly an unattractive industry in Florida where the tourist industry is at least 10 times the total value of the phosphate industry which is destroying aesthetics, land, and water values in the heartland of this great tourist area. The recovery of the land finds a ready market for this area having such great and steady influx of new settlers.

Of greatest importance is the program to find a commercial way of utilizing the slimes to produce products of large volume utilization and relatively low cost. This has been solved with eminent success by this project of IMC by the use of the slimes for the production of structural clay products, including bricks, sewer tiles, roofing tiles, artificial light-weight aggregates for use with cement in making concrete, etc. This area of study has been the one pursued to the greatest extent in your work and seems to have had major preliminary success and major possibilities for realization of commercial success within a couple of years of further engineering design and commercial development on an industrial scale.

Still another industry which would also require large volumes of material - also in the building field - would be in making portland cement. The solids of these slimes represent a possibility as one of the two basic feed components in the manufacture of portland cement - the clay or argillaceous constituent. Unfortunately, there is in Florida no substantial amount of the other principal component for portland cement production, calcareous or lime materials. Not only in Florida, but most of the southeastern seacoast of the United States and for some distance inland, is substantially free of deposits of limestone or other calcareous materials for this use in cement making.

An engineering analysis might well be made, however, with regard to the combination with these slimes solids of the almost infinite supply of aragonite, a type of calcium carbonate or limestone, which forms the basis of the shoals surrounding and making up the Bahamian Islands. There are relatively minor amounts of coral which tend to form the backbone of some of these islands; however, vast areas, both on the islands themselves and in the shoals surrounding the islands, give a practically pure aragonite when washed free of the salt water.

The tremendous deposits of aragonite filling the sea to make the shoals and thence of the islands come about due to the interesting changes in the physical chemical properties of calcium carbonate dissolved in sea water. Above a critical point of temperature of about 25-30°C there is a change in the solubility, also of the crystalline structure from the normal calcium carbonate, to give aragonite. The very cold, lime-saturated waters at the ocean depths come down from the Arctic regions, rise as they are being warmed in the Torrid Zone, and then flow back north in the Gulf Stream. Particularly noticeable in this phenomenon in the Bahamian area - especially the so-called "Tongue of the Ocean" - a deep of 5000+ feet of cold water flowing south, warming, and rising at the southern end. Here the calcium carbonate, in crystallizing out slightly above 30°C, comes out as aragonite.

In other work known to this writer, the economics of shipping tens of thousands of tons of this lime material to the mainland coast has been studied for other reasons; and it might be desirable to consider this bringing in of aragonite to use in conjunction with the clay and related materials of the slimes in the production of cement, presumably by a wet process at a point selected as optimal from considerations of transportation. The first costs of cement making are the preparation of raw materials. Often this requires mining, crushing, and grinding of hard rock. Here these expensive steps would be eliminated due to the fact that both the materials would be available in very fine form, with very low initial preparation or processing cost. The distance to such workable deposits of aragonite would be not more than 250 miles by airline from the slimes, but probably twice as much barging would be required, either for aragonite from the Bahamas to Florida, or concentrated slimes to the Bahamas. In the handling of the aragonite, it would be possible to do this with a minimum of water transport as compared to the semi-solid slimes freed of as much water as possible by sedimentation.

The Contractor

The present program, currently being evaluated, seems to have been developed under very particularly favorable conditions because of the background of IMC, with its several divisions, including the Phosphate Division producing the slimes in question, and the great expertise of this Division over many years in producing and handling these slimes. Secondly, there is, of course, the expertise of the Industrial Materials Division of IMC with its experience in drilling muds, bentonite, and other similar materials. Thirdly, and particularly the Lavino Division of IMC has had long experience in production and sales of bricks for special industrial purpose.

The contractual arrangement then developed with Illinois Institute of Technology Research Institute (IITRI) brought into the IMC team under your leadership the longtime background of this group in research in the development of special materials in the ceramics and related industries.

Mechanical Operations

Practically all of the experience of IMC and other phosphate rock producers is with the dilute slimes containing only a few percent of solids and coming from the flotation operations involved in the production of a concentrate.

Pumps - Suitable pumps have had to be developed to handle the slime solids in concentrates of up to slightly over 30%, which might be regarded as an almost equilibrium value between solids and liquids in this system of a practically permanent colloidal nature. Thus, if there was used material from the storage pond of many years accumulation, it might amount to about this concentration. The development of a pumping system was thus an urgent necessity and has been successfully accomplished.

Dryers - As a first requisite in handling the colloidal material present in a maximum concentration of about

25-30%, there is the necessity before almost any use can be made of the material of drying this to a low or negligible water concentration. (One exception to this requirement might be in its wet processing in the production of portland cement.) A major program has been carried on for the drying of the phosphate slimes utilizing several different types of dryers which seemed to have potentials for this purpose.

Pilot plant dryers have been built and very successfully operated under this program on a basis which seems to give reasonable costs for the production of large volumes of low value material. Thermal efficiencies have been achieved which are substantially equivalent to those of the dryers of similar type in other industries working with materials having much less difficult properties. This part of the program can be regarded as adequately solved.

Production of Ceramic Products

The Ceramic Laboratories of the IITRI have conducted a thorough investigation which has been eminently successful in producing bricks and sewer tile of satisfactory qualities, to compete with those currently on the Florida markets.

It should be noted that there are no other companies producing clay products for building purposes in Florida, and thus the materials now dominating the Florida market come from Georgia, and have as an overhead charge the cost of the major freight and related transportation costs. It is obvious that these relatively high costs per unit of value of such heavy materials would serve as an economic umbrella over any Florida industry producing a clay product, bricks, sewer pipe, floor or wall tile, roofing tile, etc. Substantially, the early production is planned to consist of bricks and sewer pipe. Other clay products would be added as it became possible and profitable to expand the line.

At this stage of the program which has been in progress for something less than two years, there seems to be complete success in the production of ceramic products of acceptable and reproducible quality and at a competitive price as to commercial usage. The various specifications of the American Society for Testing Materials (ASTM) have been met in the products obtained as well as those of the building codes of the various Florida cities which would use the materials.

The cost of a clay products factory has been developed in conjunction with engineers of the manufacturers of the processing equipment which would be used, and others familiar with such plant costs. The production costs have also been evaluated with the help and experience in this field of industrial engineers of IITRI and IMC, basing their work on the costs which have been developed for preparation and drying of the clay for use in clay products.

It has been determined from various sources that Florida utilizes about 100,000 tons per year of such products; and a suitable plant for the phosphate industry slimes would be at about the geographic center of the peninsula part of Florida. The northern part of Florida (above about 30° latitude) would probably fall within the shipping and sales domain of clay products factories in Georgia and Alabama.

A much bigger market for a less valuable material of lower specification requirements would be obtained by the production of lightweight aggregate. This would be used in concrete construction and would compete in a market for 2 million tons now available at a price of about $4.50 per cubic yard or $7.00 per ton.

Here again the technology of production has been developed utilizing slightly modified equipment in the IITRI laboratory and the IMC's pilot plant. A pan granulator makes balls or pellets of the clay slimes of suitable water content. These pellets or agglomerates of two to six pellets each ¼" to 3/4" in diameter must have adequate strength before firing to accommodate this further processing. The very substantial strength of the finished product after firing, which produces a porous, lightweight material, meets the necessary building material specifications of both the ASTM and the building codes of the several Florida cities which might offer the major market.

With the tremendous housing needs in Florida of even the present population, and with the large increase in population currently in progress and expected for the predictable future, it is believed that there will be a very major market developed for the slime solids in this synthetic aggregate material for concrete construction, as well as that to be readily sold in brick, pipe, tile, and other related products. The sales should be excellent in the rapidly growing housing and building construction industry, and even a less than optimistic analysis indicates that it would be possible to sell the solid products of the slimes produced annually by the entire phosphate industry of Florida.

The economics of such a venture are, of course, greatly helped by the negative value of the starting material. Very substantial by-products are the water values and especially the land values obtained in the almost explosive Florida real estate demand for plots for residences, marinas, and related non-manufacturing uses.

Future Program

A further evaluation of the economics of the programs operated to date is advisable to assure the correctness of the very apparent markets for products which could be developed from these slimes, with the larger markets being in synthetic aggregate and a smaller market at a higher price in specification grade bricks, sewer tile, floor and wall tile, and other clay products.

A production plant for making both aggregate and bricks, pipes, etc., should be built and operated to demonstrate the application to the utilization of clay slimes of these methods and the industrial system of their manufacture and distribution.

The methods and conclusions developed by the contractual work so far of IMC in the production of valuable materials from polluting materials must be utilized on a large scale. These pollutants have a very substantial dollar cost of disposal and have so far left a permanent scar on the landscape, and a large cost of land thereby wasted in their practically permanent storage. The promise of their utilization to give increasing profits, as well, to a depressed industry is an equally valuable aspect which should be studied exhaustively to its conclusion with all possible promptness and diligence.

Fortunately all of the expected markets are of a very major tonnage size, commensurate with the hundreds of millions of tons of back stock and tens of millions of tons of annual production within a very short radius. It is believed that the building industry, which must develop greatly in Florida within the next years, can use all of these slimes solids as fired clay products - bricks, sewer and other tiles, and synthetic aggregates for concrete. Even larger amounts may be used in combination with aragonite from the Bahamian area for the production of portland cement, if the transportation problems can be solved.

I understand that this project is expected to continue to demonstrate with commercial success the results so far attained.

My investigation of its various aspects, and my knowledge and experience in several of the related fields gives me confidence that your work will indeed demonstrate within another two or three years of operation on a larger scale how this major pollution and waste of natural mineral resources, of land, and of water, may be stopped with a profitable industry standing in its place.

Finally, and in closing, I would like to congratulate IMC, and particularly you as the director of this project, as well as also the Department of the Interior for its substantial financial backing. Such success in the demonstration of such profitable methods of solution of pollution problems is not often encountered and must be commended highly, particularly within such a short time and at such a minor cost compared to the values demonstrated.

Sincerely yours,

DONALD F. OTHMER

APPENDIX B

TYPICAL CALCULATIONS FOR FLUID-BED DRYER

APPENDIX B

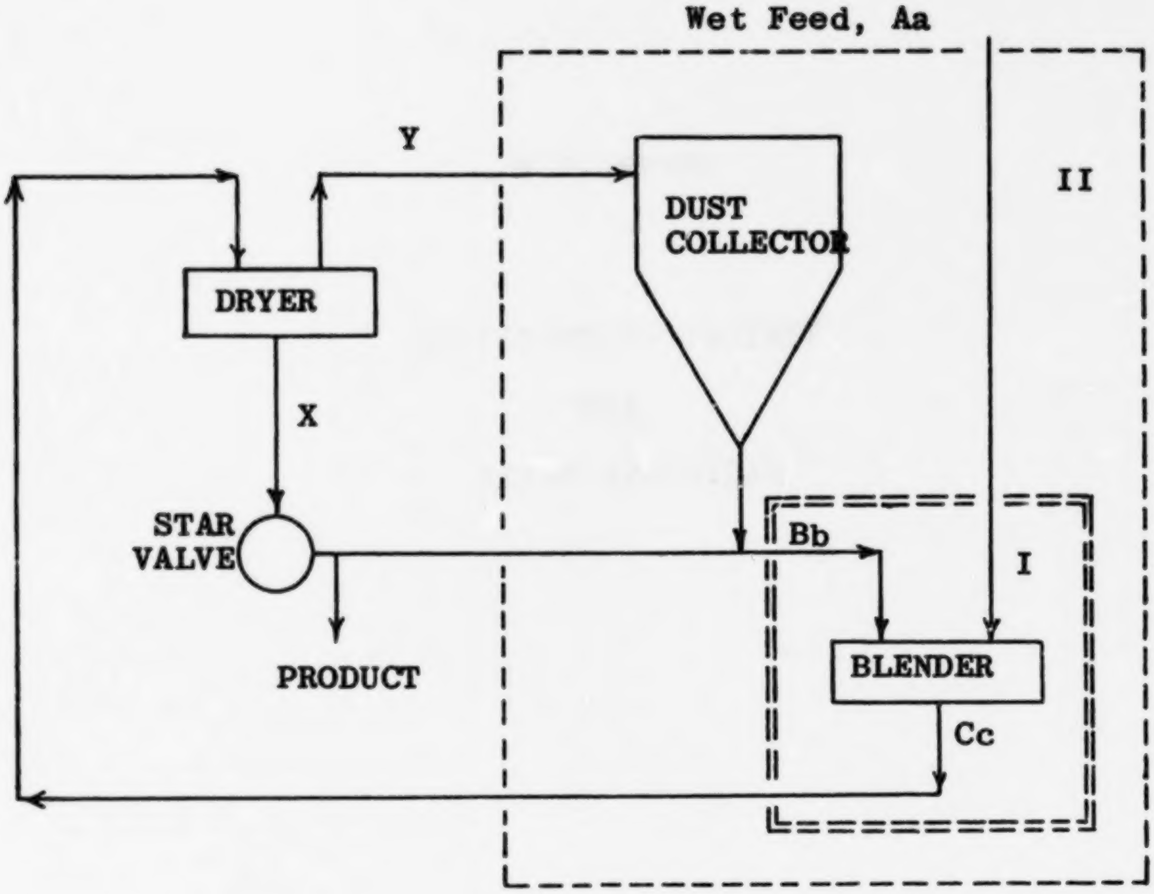
Wet Feed, Aa
Y
II
DUST COLLECTOR
DRYER
X
STAR VALVE
Bb
I
PRODUCT
BLENDER
Cc

Figure 1. FLOW DIAGRAM OF DRYING SYSTEM WITH DRY RECYCLE

X = Dryer Discharge, lb/hr
Y = Dust Loading, lb/hr

TYPICAL CALCULATION OF RECYCLE RATIO FOR 2 SQ. FT. FLUID-BED DRYER

Assume: Moisture content of dryer discharge is the same as dryer overhead product to Dust Collector.

Then:

c, Moisture in Blender Discharge = 17% H_2O
Star Valve delivers 0.15 cu.ft/rev.
A, Feed Rate = 249 lbs/hr
a, Feed Moisture = 79%

Overall material balance around blender

A + B = C

Where: A = Wt. of Feed = 250 lbs.
B = Wt. of Recycle
C = Wt. of A & B

Moisture Balance

A(a) + B(b) = C(c)

Where: a = Fraction H_2O in A = 0.79
b = Fraction H_2O in B = 0.096
c = Fraction H_2O in C = 0.17

250 + B = C
0.79(250) + 0.096B = 0.17C

0.79(250) + 0.096B = 0.17 (250 + B)

197 + 0.096B = 42.5 + 0.17B

154.5 = .074B

$$\frac{154.5}{0.074} = B$$

2087 lbs = B

$$\text{Recycle Ratio} = \frac{2087}{250} = 8.3 \ \frac{\text{lb Recycle}}{\text{lb Wet Feed}}$$

TYPICAL CALCULATION OF DUST LOADING ON BAG DUST COLLECTOR

Assume: Moisture content of dryer discharge is the same as dryer overhead to Dust Collector.

Given: From previous calculation B = 2087 lbs
Star Valve discharges 0.15 $\frac{\text{cu.ft}}{\text{rev.}}$
Density dry product - 64 lbs/ft^3

Overall Material Balance Around Recycle System

$X + Y = B$

Where: X = lbs Discharge from Dryer

Y = lbs Discharge from Dust Collector

$$X = 3\,\frac{\text{Rev}}{\text{Min}} \times 60\,\frac{\text{Min}}{\text{Hr}} \times 0.15\,\frac{\text{cu.ft.}}{\text{Rev}} \times 64\,\frac{\text{lbs}}{\text{cu.ft.}}$$

$3(60)\ (64)\ (.15) = 1730$ lbs/hr

Y = Dust Loading = $B = X$

$Y = 357$ lbs/hr

$$\frac{357 \text{ lbs dust to collector}}{250 \text{ lbs wet feed}} = 1.43$$

APPENDIX C

ANALYSIS OF FLUID-BED DRYING OF PHOSPHATE SLIMES

By

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DATA SHEET #1

MASS BALANCE

Basis: 180 lbs. of wet solids at $70^{o}F$

Water Removed = 124.2 - 1.5 = 122.7 lb.

Air leaving at $160^{o}F$
Water content of satd. Air = $0.2990 \ \frac{\text{lb. } H_2O}{\text{lb. dry air}}$

Minimum air required = $\frac{122.7}{0.2990}$ = 410 lbs. of dry air

HEAT BALANCE

1) Heat required to heat the Clay to $160^{o}F$
(55.8) (0.22) (160-70) = 1,110

2) Heat required to heat water to $160^{o}F$
(124.2) (1.0) (160-70) = 11,160

3) Heat required to evaporate 122.7 lbs. of water (122.7) (1000) = 122,700

134,970 BTU

Heat Supplied by Air

(530-160) (382) + (500-160) (324) + (328-160) (406) +

(260-160) (388) x 0.237 = 85,000 BTU

GENERAL ANALYSIS

MASS AND ENERGY BALANCES

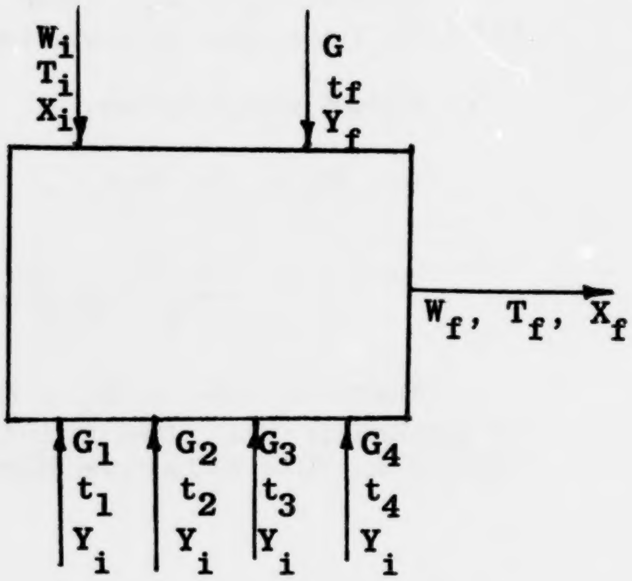

Figure 1

$W_i = W_f$ = lbs/hr of solids on dry basis

G = lbs/hr of dry air = $G_1 + G_2 + G_3 + G_4$

Y_i = $\frac{\text{lbs of water}}{\text{lb of dry air}}$

X_i = $\frac{\text{lbs of water}}{\text{lbs of dry solids}}$ at inlet

X_f = $\frac{\text{lbs of water}}{\text{lbs of dry solids}}$ at outlet

T = Temperature of solid

t = Temperature of gas

T_b = Temperature of the dryer bed

Data:

Specific heat of air = 0.237 $\frac{\text{BTU}}{\text{lb }^{\circ}\text{F}}$

Specific heat of solids = 0.22 $\frac{\text{BTU}}{\text{lb }^{\circ}\text{F}}$

Specific heat of water = 1.00 $\frac{\text{BTU}}{\text{lb }^{\circ}\text{F}}$

A) Minimum Air Requirement from Mass Balance:

Assume $T_f = t_f$; from the psychometric chart we can find Y_f from the saturation line

$$\text{Water evaporated} = X_i W_i - X_f W_f$$

$$(X_i W_i - X_f W_f) = G_{min} (Y_f - Y_i)$$

$$G_{min} = \frac{(X_i W_i - X_f W_f)}{(Y_f - Y_i)}$$

Where $G = G_1 + G_2 + G_3 + G_4$ Y_i can be estimated by assuming that the inlet air was heated from room temperature ($70^{o}F$) at 60% Relative Humidity = $Y_i = 0.01 \ \frac{\text{lbs } H_2O}{\text{lb dry air}}$

B) Minimum Heat Requirement:

Assume $T_b = T_f = t_f$

Minimum Heat Required = Heat required to raise temperature of solids to T_f and heat required to raise temperature of water to T_f + heat required to evaporate water at t_f + losses.

Heat Required = $0.22 (1 - X_i) (W_i) (T_f - T_i) + 1.0 (X_i) (W_i)$ $(T_f - T_i) + (1000) (X_i W_i - X_f W_f)$ + losses

Heat Supplied = $0.237 \left[(t_1 - t_f) G_1 + (t_2 - t_f) G_2 + (t_3 - t_f) G_3 + (t_4 - t_f) G_4\right]$

C) Thermal Efficiency

$$+ \frac{\text{Heat Reqd.}}{\text{Heat Supplied}} \times 100$$

I. Estimation of Minimum Air Requirement for Mass Transfer

Run #2 (Typical calculation)

150 lbs/hr of wet feed = (74.3% H_2O
(25.7% Solids

41.3 lbs/hr of product = (6.7% H_2O
(93.3% Solids

108.7 lbs H_2O evaporation

Minimum Air Required

Air leaving at 122°F

Saturated water content at 122°F = $0.08678 \frac{\text{lbs } H_2O}{\text{lb dry air}}$

If inlet air 60% satd. at room temperature before heating, its water content = $0.01 \frac{\text{lbs } H_2O}{\text{lb dry air}}$

108.7 lbs H_2O evaporated.

Minimum Air = $\frac{108.7}{0.08678-0.01}$ = $1420 \frac{\text{\# air}}{\text{hr.}}$

Air Used = 1305 #/hr.

II. Estimation of Actual Gas Flow Rates Used

The actual gas flow rates for each run was calculated by averaging the inlet temperatures in the four compartments and averaging the pressure drop in them. The calibration curve supplied with the data sheets was used to calculate gas flow rate in C.F.M. at 7° F and was converted to #/hr.

TABLE I - Gas Flow Rates Calculated from Operating Data

Run #2 (Typical calculation)

Compartment	$\overline{T_b}$ °F	$\overline{\Delta P}$ (in.H_2O)	G (CFM) (@ 7°F)	G $\frac{\text{(lbs)}}{\text{(hr.)}}$
1	427	0.21	60	307
2	421	0.21	60	307
3	328	0.24	75	384
4	293	0.16	60	307

ΣG = 1305 #/hr

III. Calculations for Fluidization Air Required

The procedure recommended by Leva (Ref. 1) in his book was used. (Page 67)

The average diameter $\overline{D_p}$ was calculated on wt. fraction basis.

$$\overline{D_p} = \frac{1}{\sum_i \frac{X_i}{d_{pi}}}$$

(Where X_i is the wt. fraction of particles of size d_{pi}.)

The pressure drop in the packed bed can be found by knowing the unit density and bed volume and area.

$$\Delta P = \frac{\text{Unit density x Volume (cuft)}}{\text{Area (sq. ft)}}$$

The density of inlet air at a specified temperature and at a pressure of $P = P_{atm} + \Delta P$ was calculated. Using this ρ_{air} $(\rho_p - \rho_{air})$ was calculated.

Viscosity of air at the inlet was estimated from Perry's handbook.

The nomograph from Leva's book was used to estimate the minimum fluidization gas flow rate in $lbm/hr\ ft^2$.

(7)

SCREEN ANALYSIS OF SLIMES (PRODUCT)

	Tyler Mesh
5%	6
10%	8
18.7	9
61.5	14
81.5	20
95.5	35
99.7	100
100	-100

TABLE II - Calculation of Average Diameter

Tyler Mesh No.	Opening dia.	d_{pi} (inches)	X_i
		0.1500	0.05
+ 6	0.131		
		0.1120	0.05
8	0.093		
		0.08505	0.087
9	0.078		
		0.0620	0.428
14	0.046		
		0.0394	0.200
20	0.0328		
		0.0246	0.140
35	0.0164		
		0.0111	0.042
100	0.0058		
		0.0050	0.003
- 100			
			1.000

$$\sum_i \frac{X_i}{d_{pi}} = \frac{0.05}{0.15} + \frac{0.05}{0.1120} + \frac{0.087}{0.08505} + \frac{0.428}{0.0620}$$

$$+ \frac{0.200}{0.0394} + \frac{0.140}{0.0246} + \frac{0.042}{0.0111} + \frac{0.003}{0.005}$$

0.333
0.446
1.021
5.080
5.700
3.790
0.600
16.970

Average Diameter $\overline{D_p} = \frac{1}{16.970} = 0.059$ inch

Fluidization Air Required

Run #2 (typical calculation)

Average temperature of 4 compartments = 367°F

$$\rho_{air} = \frac{29}{359} \times \frac{492}{(367 + 460)} = 0.048 \frac{\#}{cft}$$

$$\rho_s = 103\#/cft$$

$$\rho_{air} (\rho_s - \rho_{air}) = 0.048 \times 103 = 4.88 \frac{lbs}{cft}$$

$$\mu_{air} = 0.025 \text{ c.p.}$$

from the nomograph

Min. Fluidization Air $= 360 \frac{\#}{hr.sq.ft.} = 720 \frac{\#}{hr.}$

IV. Estimation of Air Requirement for Heat Transfer

From the heat required for heating and evaporation, Q, and the average inlet and outlet temperature the air rate is calculated.

$$Q = 0.237 \text{ (Avg. Inlet Temp. - Avg. Outlet Temp.) } G_h$$

TABLE III - Air Required for Heat Transfer

Run #	Heat Reqd.for Vaporization, BTU	$\bar{t}_i$ °F	$\bar{t}_f$ °F	Air needed for Heat Transfer (lb air/lb wet feed)
2	232,842	367	117	11.9
3	120,955	483	160	9.2
4	821,760	436	118	10.1
5	926,260	423	118	11.1

V. Heat Requirement for Water Vaporization and Calculation of Thermal Efficiency

Run #2 (typical calculation)

Heat required to raise solid temperature to 122°F

= (122-65)(0.22)(78.4) = 983.1 BTU

Heat required to raise water temperature to 122°F

= (225.6)(1.)(57) = 12,859 BTU

Heat required to evaporate water at 122°F

= (218.9)(1,000) = 218,900 BTU

Total Heat Required = 232,842 BTU

Heat Supplied (Figure from John Senft) = 494,400 BTU

$$\text{efficiency} = \frac{232,842}{494,400} = 47.2\%$$

TABLE IV - AIR REQUIREMENTS/# FEED

Run #	Feed Rate, lb/hr.	H_2O Balance Min. Air Rqd. for H_2O Balance, lb/hr.	H_2O Balance Min. Air Rqd. / # feed, # Air / # feed	Min. Fluid Air, #/hr.	Min. Fluid Air / # Feed, # Air / # feed	Actual Air Used lb/hr.	Actual #Air Used / # Feed	Air Used / Min. Fluid Air	Air Needed for Heat, # Air / # feed	Thermal Efficiency
2	150	1420	9.46	720	4.80	1305	8.70	2.83	11.9	47.2
3	169	337	2.00	640	3.78	730	4.31	1.80	9.2	55.5
4	246	3820	15.50	720	2.93	1530	6.22	3.33	10.1	79.2
5	226	1050	4.65	720	3.19	1243	5.50	2.71	11.1	62.4

V. A Theoretical Model for Calculation of Dryer Performance

Let F_i, F_f - Weight flow rates of wet solids at inlet and outlet

T - Temperature of solids

t - Temperature of gas

x - Wt. fraction of water - $\frac{\text{lbs } H_2O}{\text{lb of dry solids}}$

y - Wt. fraction of water - $\frac{\text{lbs water}}{\text{lb of dry air}}$

T_b - Temperature of the bed

T_p - Temperature of the particle in the bed.

The model used here to analyze the dryer performance is similar to the one discussed in Reference (2).

Consider a single wet porous particle d_p at temperature T_p. The drying rate is given by

$$-\left(\frac{\pi}{6} d_p^3\right) \rho_s \, dX = \pi d^2 \, K_g \, (Y^x - Y_f) \, dt = \frac{\pi d_p \, hp \, (T_b - T_p) \, dt}{\lambda} \qquad (1)$$

The left hand size of Eqn. (1) represents the loss of free moisture content. The first term on the right hand side represents the mass transfer from the wet particle to the gas and the second term represents the heat transfer to the particle.

Here λ = latent heat of vaporization

Y^x = equilibrium moisture content

h_p = heat transfer coefficient

k_g = mass transfer coefficient

Therefore

$$-dX = \frac{6hp \ (T_b - T_p)}{\rho x \ d_p \ \lambda} \ dt \qquad (2)$$

For constant rate drying of wet porous particles, the temperature of the particles remain close to the wet bulb temperature of the gas in the bed, i.e. for constant ΔT and for $X = X_i$ at $t = 0$

$$\frac{X}{X_i} = 1 - \frac{t}{\tau} \qquad (3)$$

Where $\tau = \dfrac{P_s d_p X_i \lambda}{6 \ hp \ (t_B - T_p)}$

τ has a dimension of time = time needed to completely dry a feed particle. Now the residence time of particles in each compartment is approximated by

$$\bar{t}_j = \frac{\text{wt. of bed in each compartment}}{\text{Avg. flow rate of solids}} = \frac{W_j}{\frac{F_i + F_f}{2}} \qquad (4)$$

or the average residence time of particles is

$$\bar{t} = \frac{W}{\frac{F_i + F_f}{2}} \qquad (5)$$

(14)

The distribution of residence time of particles is given by

$$E\ (t) = \frac{1}{\bar{t}} \quad e^{-\ t/\bar{t}} \quad \text{(Eqn. 11.3 in Ref. 2)}$$

The residence time distribution as given by the above equation is exponential in nature. This distribution is sketched in Figure 2.

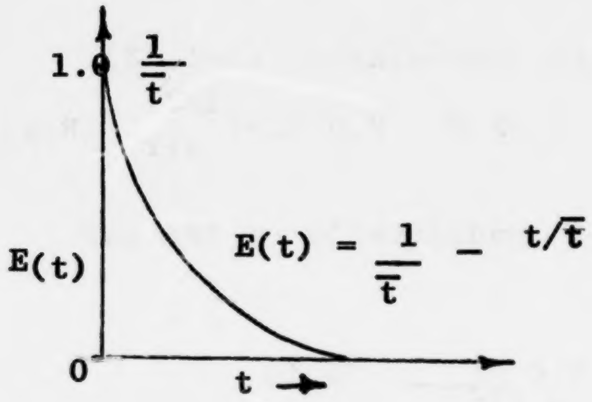

Figure 2 - Residence time distribution of particles in dryer.

Average moisture content is given by

$$\bar{X} = \int_{t = 0}^{t = \tau} X \ E(t)\ dt$$

Therefore

$$\frac{X \text{ outlet}}{X \text{ inlet}} = 1 - \frac{1 - e^{-\tau/\bar{t}}}{/\bar{\tau}} \qquad (6)$$

or for each compartment

$$\frac{X_j \text{ outlet}}{X_j \text{ inlet}} = 1 - \frac{1 - e^{-\tau_i/\bar{t}_j}}{\tau_j/\bar{t}_j} \qquad (7)$$

The final moisture content can be calculated by a progressive procedure from one compartment to the next with the exit moisture content of the solids leaving one compartment as the inlet moisture content for the next compartment. Equation (7) is used to calculate the moisture content leaving a given compartment.

1. Estimation of Heat Transfer Coefficient

Using Ranz-Marshall correlation (Ref. 3)

$$(Nu)_p = \frac{h_p d_p}{K_g} = 2.0 + 0.6\,(Pr)^{1/3}_{air}\,(Rep)^{\frac{1}{2}} \qquad (8)$$

where K_g = thermal conductivity of the gas

$dp = 0.059''$

$K_g = 0.22\ \frac{BTU}{hr\ ft^2}\ {}^{o}F/ft$

$(Pr)^{1/3}_{air} = (0.7)^{1/3} \approx 1.0$

$Rep = \frac{dpU}{\nu\ air}$

Av.Flow = 70CFM => $U \approx 2.3$ ft/sec.

$Rep \approx 70$

Therefore from Eqn. (7)

$hp \approx 18.6\ \frac{BTU}{ft^2}\ {}^{o}F\ hr$

2. Calculation of τ =

$$(103 \times \frac{.059}{.2} \times X_i \times 1000)/6 \times 18.6(T_{jB} - T_p) \qquad (9)$$

3. Estimation of the weight of bed in each compartment

The volume of each compartment can be estimated from the appropriate dimensions given.

Wt. of bed in each compartment

= volume of compartment x unit density of particles x fraction of bed occupied by particles under no fluidization condition

$$W = 4\ ft^3 \times \frac{64\ lb}{ft^3} \times 0.25 = 64\ lb$$

Run #2 (typical calculation)

Feed Rate = 150#/hr of wet solids = F_i

Product Rate = 41.3 lbs/hr = F_f

$$\text{Residence time} = \bar{t}_j = \frac{W}{\frac{(F_i + F_f)}{2}} = \frac{64}{(150 + 41.3)} =$$

0.667 hr. in each compartment

$$X_i = \frac{74.3\ \#\ water}{25.7\ \#\ dry\ solids} = 2.89$$

Water Evaporated = 108.7 lb H_2O

T_p = 117°F

T_{1B} = 120.8°F

T_{2B} = 132.0°F

T_{3B} = 135°F

T_{4B} = 137°F

The mass flow rate of air G $\approx$ 1420

SUMMARY OF RESULTS AND CONCLUSIONS

1. The ratio of air used to air required for minimum fluidization varied from 2.93 to 4.8.

2. The ratio pound of air needed for heat transfer to pound of feed varied from 9.2 to 11.9.

3. The ratio of pound of air used to pound of feed varied from 4.31 to 8.70.

4. The ratio of air need for water vaporization to pound of feed varied from 2.0 to 15.5.

5. The thermal efficiency varied from 47.2% to 79.2%.

6. With the possible exception of Run #4, the calculated results as presented in Table IV, indicate that heat transfer is controlling in the present runs.

7. A theoretical model based on the constant drying rate period was devised and it successfully predicted the experimental values for the final moisture content. The agreement is better than should be expected. The close agreement between the theoretical and experimental values for Runs 2 and 3 verified the assumption that the heat transfer is controlling.

8. The model clearly indicates that the drying time can be reduced by increasing the difference between the bed temperature and the particle temperature. This can be conveniently achieved by increasing the inlet gas temperature. Thus by decreasing the drying time higher throughput can be achieved. The results of Run #3 which employed a gas temperature of 483^{o}F verify this prediction.

9. The theoretical calculations using the proposed model predict that comparing Runs 2 and 3, the better drying is accomplished in Run #3. The experimental data support this conclusion.

10. Finally, it should be pointed out that the gas flow rates were estimated from the calibration curve and these values could be in error by at least ± 20% due to the nature of the calibration chart. (See Figure 2.) For example, for Run #2, an air flow rate of 1305 lb/hr was estimated using the calibration curve. The minimum air flow rate required for water balance is 1420 lb/hr. The latter value differs from the former by less than 10%, and this deviation is considered to be within the accuracy of the interpolation.

11. The data for most of the runs indicated an unsteady state operation. Furthermore, the data on the bed temperature was found to be inconsistent. For example, for Runs 4 and 5, the bed temperature was found to be lower than the temperature of the particles which are assumed to be at the wet bulb temperature of the exhaust stream. Therefore, no attempt was made to calculate the theoretical moisture concentration in the dryer for these two runs.

12. The inlet humidity content of the gas was unknown. However, this value is needed to calculate theoretical moisture content. Therefore, a value of 0.01 $\frac{\text{\# water}}{\text{\# dry air}}$ which corresponds to 60% relative humidity in room air at 70°F was assumed.

RECOMMENDATIONS

It is stated that in order to develop a more realistic procedure for the analysis of the dryer data the following recommendations be considered:

1. The inlet and outlet humidity of all the gaseous streams be recorded.
2. Gas flow rates be accurately recorded.
3. Amount of solids in each compartment be determined.
4. Drying characteristics of the wet material to be dried be determined in a separate bench scale experiment.
5. The ratio of air used to air required for minimum fluidization should be approximately equal to 1.5 to 2.0.

With these additional data, a more thorough analysis for the drying operation be carried out.

REFERENCES

1. Leva, Max, "Fluidization," McGraw-Hill Book Company, Inc., N.Y., (1959), page 67.

2. Kunii, Daizo and Octave Levenspiel, "Fluidization Engineering," John Wiley, New York, (1969), pages 443-446.

3. Ranz, W. E. and W. R. Marshall, Chem. Eng. Progr., Vol. 48, 141, (1952).

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APPENDIX D

TRANSPORTATION STUDY
OF
LIGHTWEIGHT AGGREGATES

APPENDIX D

TRANSPORTATION STUDY OF LIGHTWEIGHT AGGREGATES

PROBLEM (1) To determine the best distribution plan for our lightweight aggregate product. Comparison of shipping lightweight aggregate from Bartow to consumer with shipping dried slimes to satellite kilns.

PROBLEM (2) To determine transportation costs.

TABLE I

Given:

(1)

Freight Rates from Bartow to:	Open Hopper* Car Rates	Closed Hopper* Car Rates
Tampa	$1.10/net ton	$2.25/net ton
Jacksonville	2.27/net ton	3.36/net ton
Miami	2.27/net ton	3.36/net ton

(2) Minimum car loading = 80,000 lbs.

(3) Cars available = 1968 cu.ft. hoppers (50 ton)
3500 cu.ft. hoppers (100 ton)

(4) Lightweight aggregate can be shipped in open hoppers.

(5) Dried slimes (64 lbs/cu.ft.) must be shipped in closed hoppers.

* Supplied by IMC's Transportation Dept.

APPENDIX D (2)

Assume:

(1) Lightweight aggregate will be shipped under the same tariff as expanded shale and slag.

(2) Dried slimes will be shipped under the same tariff as expanded shale.

(3) Lightweight aggregate density may vary from 14 PCF to 40 PCF.

(4) 3500 cu.ft. hoppers have same minimum weight restriction as 1968 cu.ft. hoppers.

SOLUTION:

To determine how much it will cost to ship a material that weighs between 14 and 40 pounds per cu.ft. in a hopper car that has a minimum weight specification of 80,000 lbs per car:

Two car sizes are available, 1968 cu.ft. cars and 3500 cu.ft. cars.

For the 1968 cu.ft. car case, locate point A (Figure 1) as follows:

$$\frac{1968 \text{ cu.ft.}}{\text{car}} \times \frac{14 \text{ lbs}}{\text{cu.ft.}} \times \frac{\text{ton}}{2000 \text{ lbs}} = 13.8 \frac{\text{tons}}{\text{car}}$$

This point was plotted and a line drawn through the origin. In a like manner, the line for the 3500 cu.ft. car was determined.

Figure 1 shows that if the product-mix average density is equal to or greater than 40 lbs/cu.ft., the 1968 cu.ft. car is adequate. If, however, the product-mix is less than 40 lbs/cu.ft., there is a penalty since the low weight requirement of 80,000 lbs/car cannot be met. In the case of the 3500 cu.ft. car, the break-even point is at approximately 24 lbs/cu.ft.

To evaluate shipment of dried slimes from Bartow to a satellite kiln plant in Tampa, Miami or Jacksonville in order to take advantage of the extra density (64 PCF) and hence full hopper car criterion for this material that is available to us, break-even was determined thus:

Figures 2 and 3 were constructed as follows:

Pt. D was picked from Table I. Open hopper rate to the respective city.

Pt. E was found as follows:

The minimum rate of 40 tons, or in the case of Bartow to Tampa, is \$1.10/ton. This amounts to \$44.00 per car load. However, the car only holds 13.8 tons making the actual cost \$3.18/ton to ship. This lightweight material, \$3.18/ton, is plotted as Point E. Other points were constructed in a similar manner.

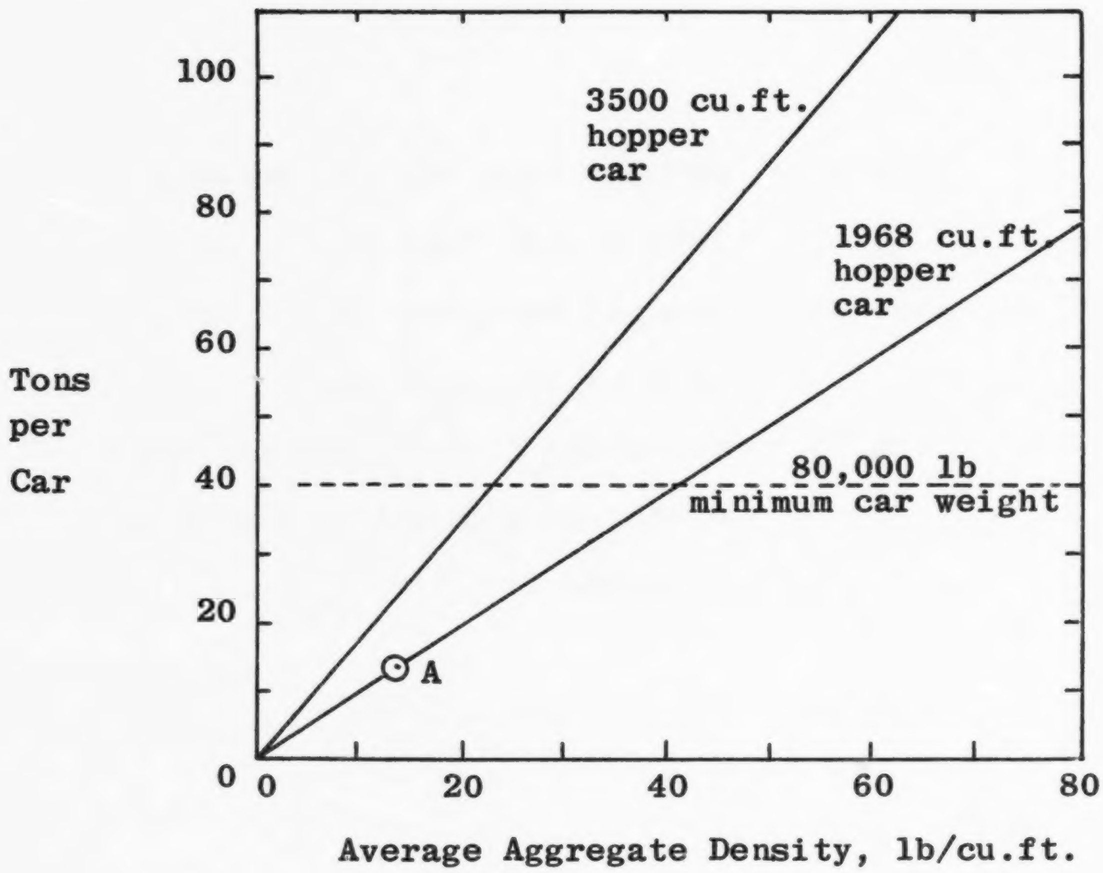

Figure 1. EFFECT OF AGGREGATE DENSITY ON CAR LOADING

Line AB = Freight Rate for LWA Using a 1968 cu.ft. Open Car.

Line ED = Freight Rate for LWA Using a 3500 cu.ft. Open Car.

Line CC′ = Operating Line Indicating Cost of Shipping Dried Slimes Using a Closed Car.

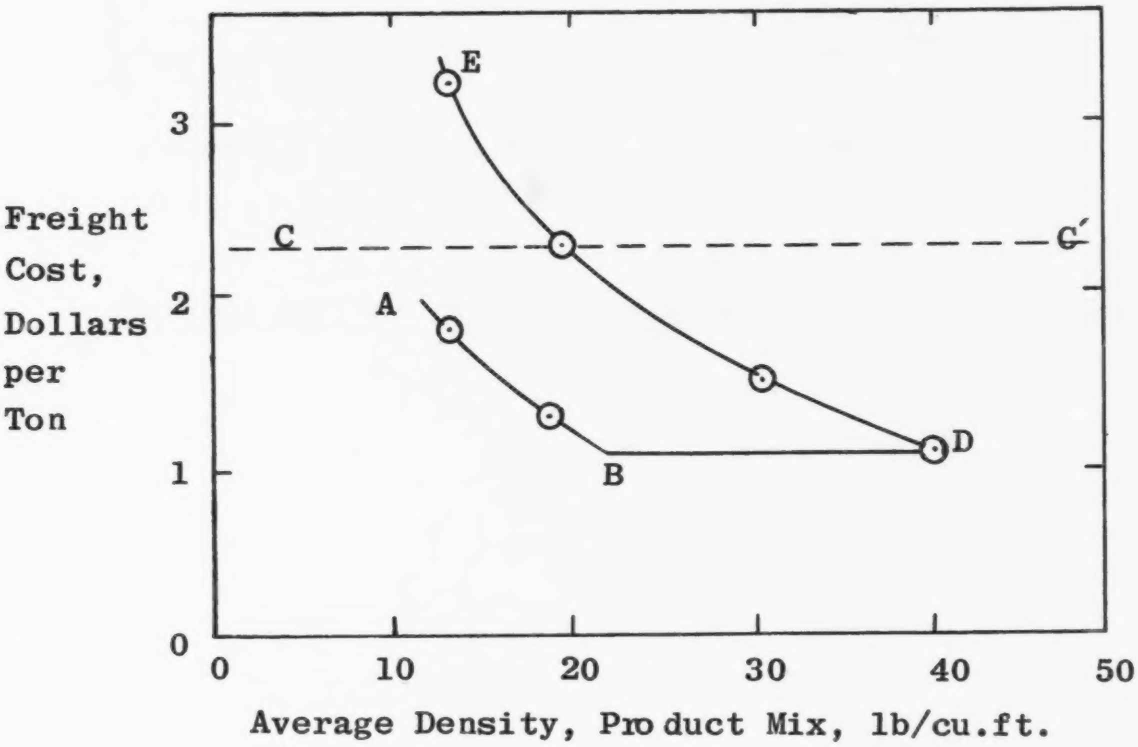

Figure 2. ESTIMATED BREAK-EVEN COST OF SHIPPING LIGHTWEIGHT AGGREGATE OR DRIED SLIMES FROM BARTOW TO TAMPA, FLORIDA.

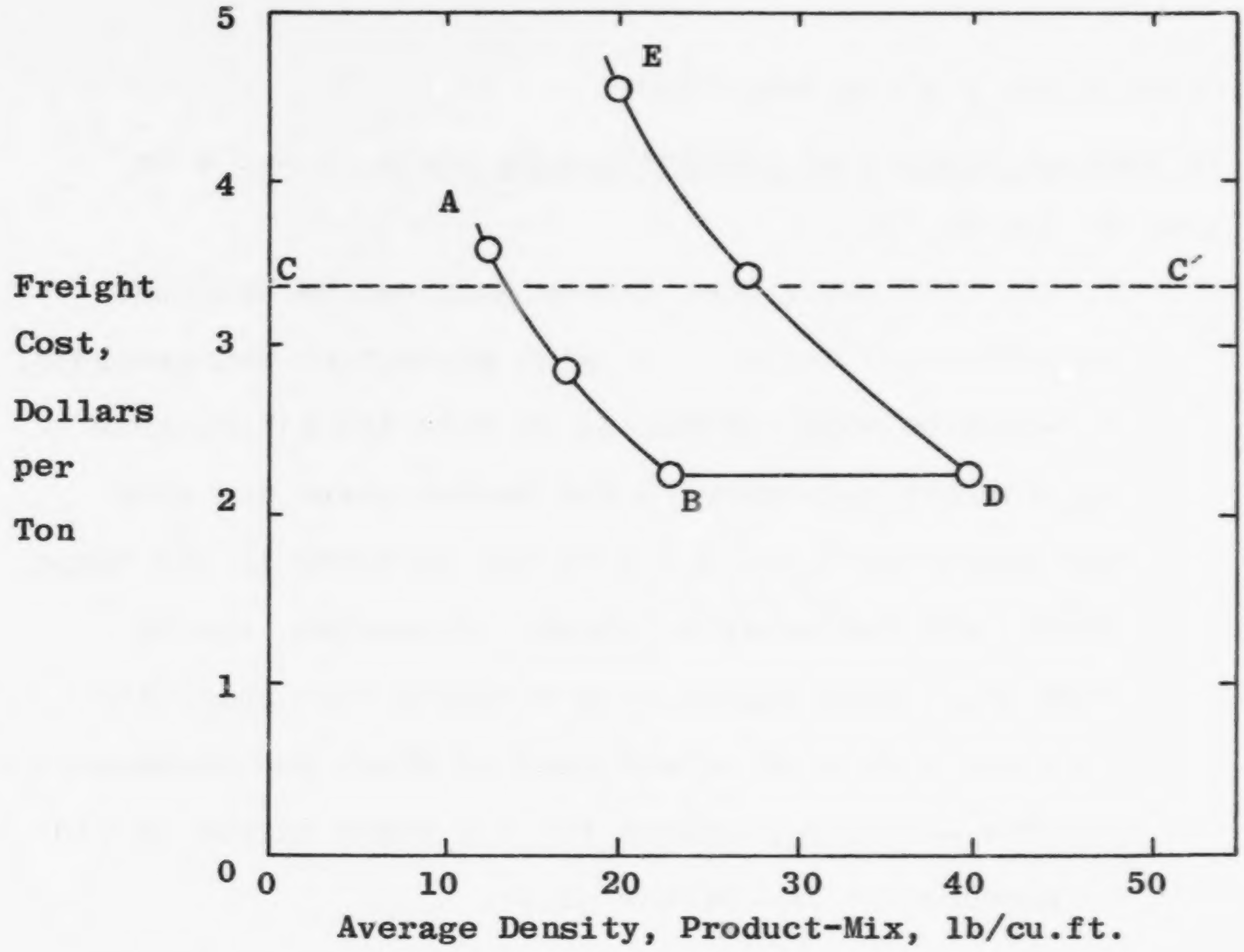

Figure 3. ESTIMATE OF BREAK-EVEN COST OF SHIPPING LIGHT-WEIGHT AGGREGATE OR DRIED SLIMES FROM BARTOW TO MIAMI OR JACKSONVILLE, FLORIDA.

Line AB = Freight Rate for LWA Using a 3500 cu.ft. Open Car.

Line ED = Freight Rate for LWA Using a 1968 cu.ft. Open Car.

Line CC′ = Operating Line Indicating Cost of Shipping Dried Slimes Using a Closed Car.

CONCLUSIONS & RECOMMENDATIONS:

If Average Density of product-mix is light, i.e., less than 28 lbs/cu.ft.

1. If 3500 cubic foot hopper cars can be obtained in sufficient quantity to meet production requirements, it would be more economical to fire the slimes into lightweight aggregate at the Bartow plant and ship the lightweight aggregate to the customer in the Tampa, Miami, and Jacksonville areas. Otherwise, use of 1968 cubic foot hopper cars suggests that satellite kiln operations be established at Miami and Jacksonville.
2. The material produced for the Tampa market should be produced at the Bartow plant.
3. The transportation difference in cost of firing the lightweight aggregate at Miami and Jacksonville location vs. firing it at the Bartow plant amounts to $3.36 per ton, the Jacksonville and Miami satellites being the cheaper alternative.

If Average Density of product-mix is heavy, i.e., greater than 28 lbs/cu.ft.

4. It will always be cheaper to produce fired lightweight aggregate at the Bartow plant.

Other Conclusions

5. It may be possible to negotiate a lower minimum

weight requirement for the cars in question, in which case economics would have to be re-evaluated.

6. A product mix study of 14 PCF material and 40 PCF material must be made.

7. The break even points shown in Figures 2 and 3 designate transportation costs only. Trade off values between production costs and these transportation costs must be made before a final evaluation as to the plant configuration can be made.

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APPENDIX E

LOCATION OF LIGHTWEIGHT AGGREGATE PRODUCERS

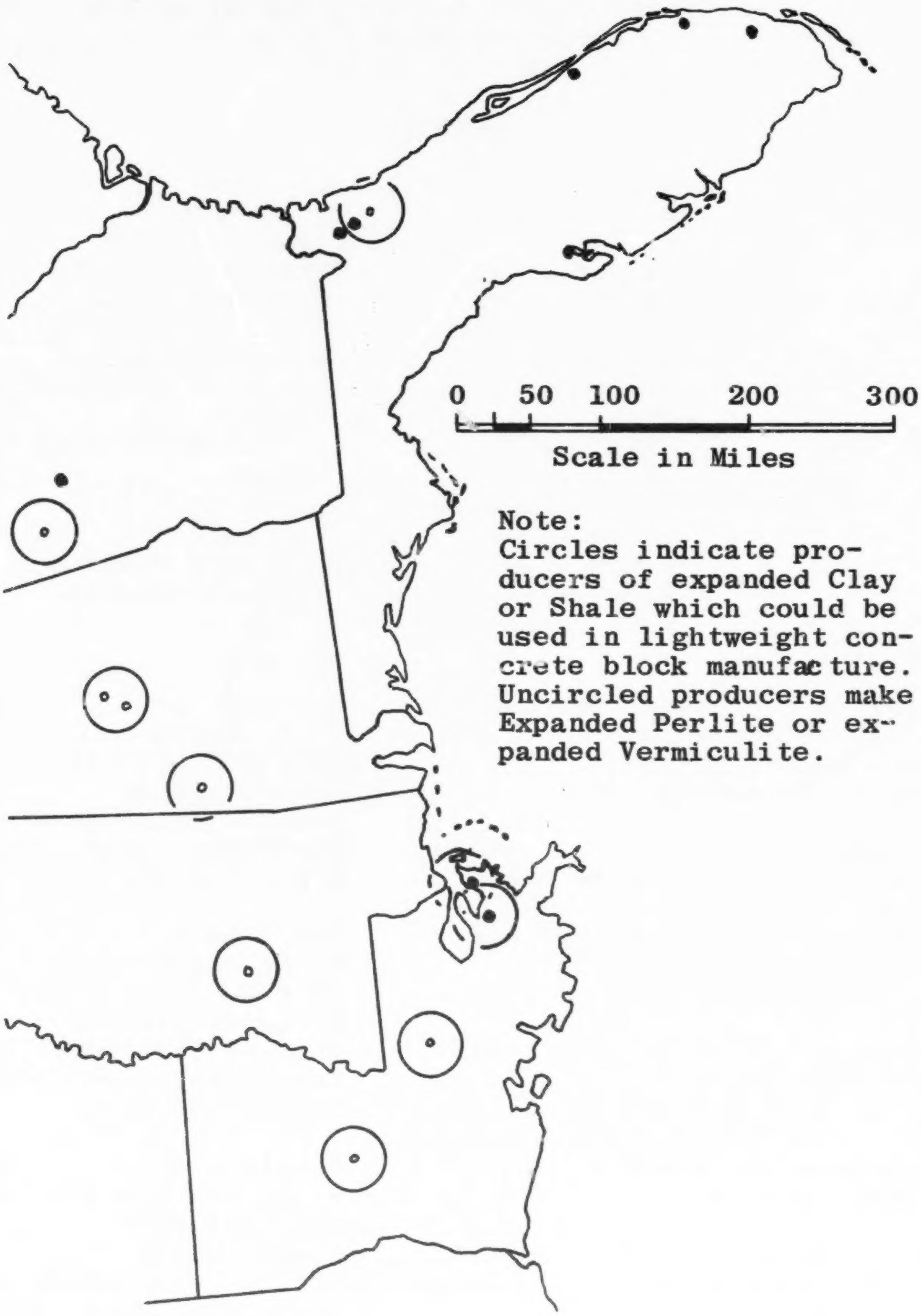
APPENDIX E

MAP SHOWING LOCATION OF LIGHTWEIGHT AGGREGATE PRODUCERS

A map showing the location of Lightweight Aggregate Producers together with an appropriate legend, is shown in Figure 1 and Table I. Note that the primary producers in the Florida area expand vermiculite or perlite. There is only one manufacturer who expands clay which is used in concrete block. Concrete block is one of the major building materials in the Florida area. From the location of this producer in the Jacksonville area, it is evident that a producer further south would have a distinct advantage since this is where most of the new construction activity is located.

The map also shows that there are no major threats to a central Florida producer anywhere in the neighboring states.

Another factor that makes a lightweight aggregate plant attractive in the mid-Florida area is that vermiculite and perlite (the raw materials for competitive lightweight aggregates), are shipped to Florida from other states like New Mexico, South Carolina, and Montana. Any slimes lightweight aggregate product that would compete with the current suppliers would not have to bear the brunt of the raw material transportation costs that is borne by vermiculite.



Note:
Circles indicate producers of expanded Clay or Shale which could be used in lightweight concrete block manufacture. Uncircled producers make Expanded Perlite or expanded Vermiculite.

Figure 1. LIGHTWEIGHT AGGREGATE PRODUCING PLANTS IN THE SOUTHEASTERN U.S., COURTESY PIT & QUARRY (1969)

TABLE I
LIGHTWEIGHT AGGREGATE PRODUCING PLANTS
(Referred to in Figure 1)

Symbols

Cin	Cinders
D	Diatomite
Ex Cl	Expanded Clay
Ex Per	Expanded Perlite
Ex Sh	Expanded Shale
Ex Sl	Expanded Slag
Ex Slate	Expanded Slate
Ex Ver	Expanded Vermiculite
PFA	Fly Ash
SFA	Sintered Fly Ash
Pu	Pumice
Tuff	Tuff
V Ash	Volcanic Ash
V Cin	Volcanic Cinders
V Sc	Volcanic Scoria

FLORIDA

Airlite Processing Corp. ExPer
Bldg. #9 Air Base
Vero Beach, 32960
Brand: Permalite

Chemrock Corp. ExPer
Box 39 Grand Crossing Sta.
Jacksonville 32205
Off: Osage St. P.O. Box 5685
Nashville, Tenn. 37204
Brand: Tensulate

Florida Solite Co. ExCl
P.O. Box 297
Green Cove Springs 32043
Off: 1114 SCL Railway Bldg.
Jacksonville 32202
Brand: Solite

Zonolite Div. ExVer
W. R. Grace & Co. ExPer
P.O. Box 67
Boca Raton 33432
Off: 62 Whittemore Ave.
Cambridge, Mass. 02140
Brand: Zonolite

FLORIDA

Zonolite Div. ExPer
W. R. Grace & Co.
1050 S.E. 5th St.
Hialeah 33010
Off: 62 Whittemore Ave.
Cambridge, Mass. 02140
Brand: Zonolite

Zonolite Div. ExVer
W. R. Grace & Co.
1530 E. Adams St.
Jacksonville 32202
Off: 62 Whittemore Ave.
Cambridge, Mass. 02140
Brand: Zonolite

Zonolite Div. ExPer
W. R. Grace & Co. ExVer
P.O. Box 5047
Tampa 33605
Off: 62 Whittemore Ave.
Cambridge, Mass. 02140
Brand: Zonolite

TABLE I
LIGHTWEIGHT AGGREGATE PRODUCING PLANTS
(Page 2)

ALABAMA

Tombigbee Ltwt Aggr.Co. ExCl
P.O. Box 2
Livingston 35470
Brand: Liv Lite

U.S. Pipe & Foundry Co. ExSl
4200 Huntsville Road
Birmingham 35207
Off: 3300 1st Ave.No.
Birmingham 35202

Vulcan Materials Co. ExSl
Southeast Div. ExSh
P.O. Box 7324-A
Birmingham 35223
Off: P.O. Box 7497
Birmingham 35223

Vulcan Materials Co. ExSl
Woodward
Off: P.O. Box 7324-A
Birmingham 35216
Brand: Expanslag

GEORGIA

Georgia Ltwt.Aggr.Co. ExSh
P.O. Box 188
Rockmart 30153
Off: P.O. Box 19781,Sta.N
Atlanta 30325
Brand: Galite

Zonolite Div. ExPer
W.R. Grace & Co. ExVer
P.O. Box 8127 Sta.F
Atlanta 30306
Office: 62 Whittemore Ave.
Cambridge, Mass. 02140
Brand: Zonolite

LOUISIANA

Big River Indus.,Inc. ExCl
U.S. Highway 190
Erwinville 70729
Off: P.O. Box 66377
Baton Rouge 70806
Brand: Gravelite

Filter Media Co. ExPer
Sycamore W 10th ExVer
Box 222 V Ash
Reserve 70084
Off: P.O. Box 19156
Houston, Texas 77024
Brands: Perlite King &
Micalite

Louisiana Indus.,Inc. ExCl
4600 Lee Street
P.O. Box 5427
Alexandria 71301
Brand: Haydite

Zonolite Div. ExVer
W.R. Grace & Co.
P.O. Box 10262
New Orleans 70121
Off: 62 Whittemore Ave.
Cambridge, Mass 02140
Brand: Zonolite

MISSISSIPPI

Delta Industries,Inc. ExCl
Cynthia
Off: P.O. Drawer 1292
Jackson 39205
Brand: Miss-Lite

APPENDIX F

ESTIMATION OF CONCRETE STRENGTH FROM AGGREGATE CRUSH STRENGTH RESULTS

APPENDIX F

ESTIMATION OF CONCRETE STRENGTH FROM AGGREGATE CRUSH STRENGTH RESULTS

A chart produced from tests conducted by the National Bureau of Standards showing the relationship between various lightweight aggregate 1" compaction tests and compressive strengths of concretes produced from them after 28 days, is reproduced in Figure 1.

From Figure 1, Figure 2 was produced. Figure 2 displays data used to obtain the regression line together with the limits of accuracy. This shows relative values of concrete strengths from lightweight aggregate vs. 1" compaction tests.

The regression line used to estimate concrete strength from lightweight aggregate 1" crush strengths can be described by the equation:

$Y = MX$ or $Y = (2.75 \pm 0.4)X$

Where Y = Concrete strength after 28 days (Average for 5 & 7 bag mixes psi)

M = 2.75 ± 0.4

X = Lightweight aggregate crushing strengths (1" compaction psi)

This equation will give us a crude tool for evaluating concrete strengths from slimes lightweight aggregate crush strength values.

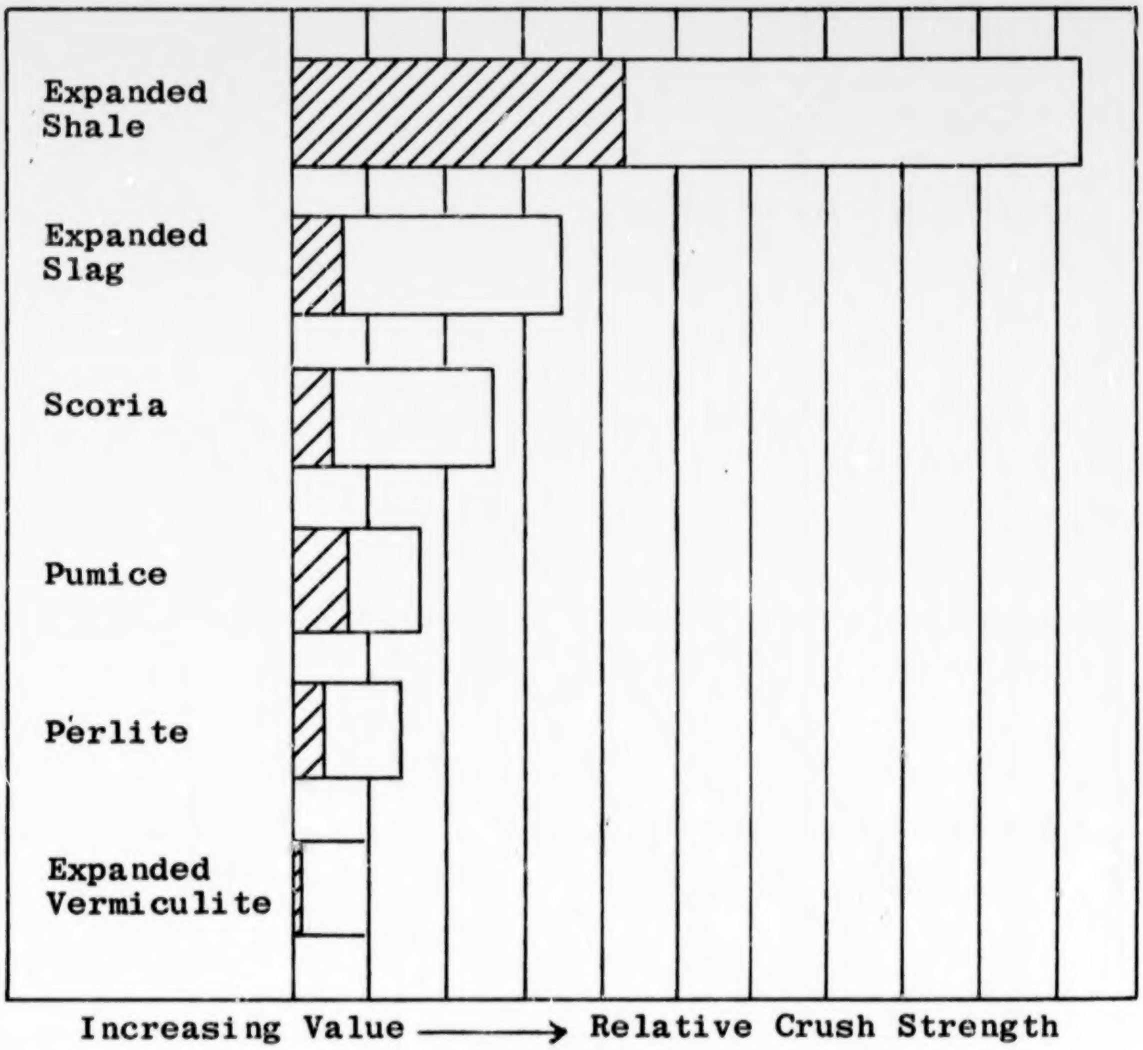


Figure 1. COMPARISON OF AGGREGATE CRUSH STRENGTH (1-IN. COMPACTION) WITH 28-DAY COMPRESSIVE STRENGTHS OF CONCRETE

Comparison of crushing strength of aggregate to compressive strengths of concrete. From tests conducted by National Bureau of Standards. The solid block denotes the aggregate average strength for 1-in. compaction; the white area indicates the concrete (average of 28-day strengths for five and seven-bag mixes). Courtesy of Rock Products.

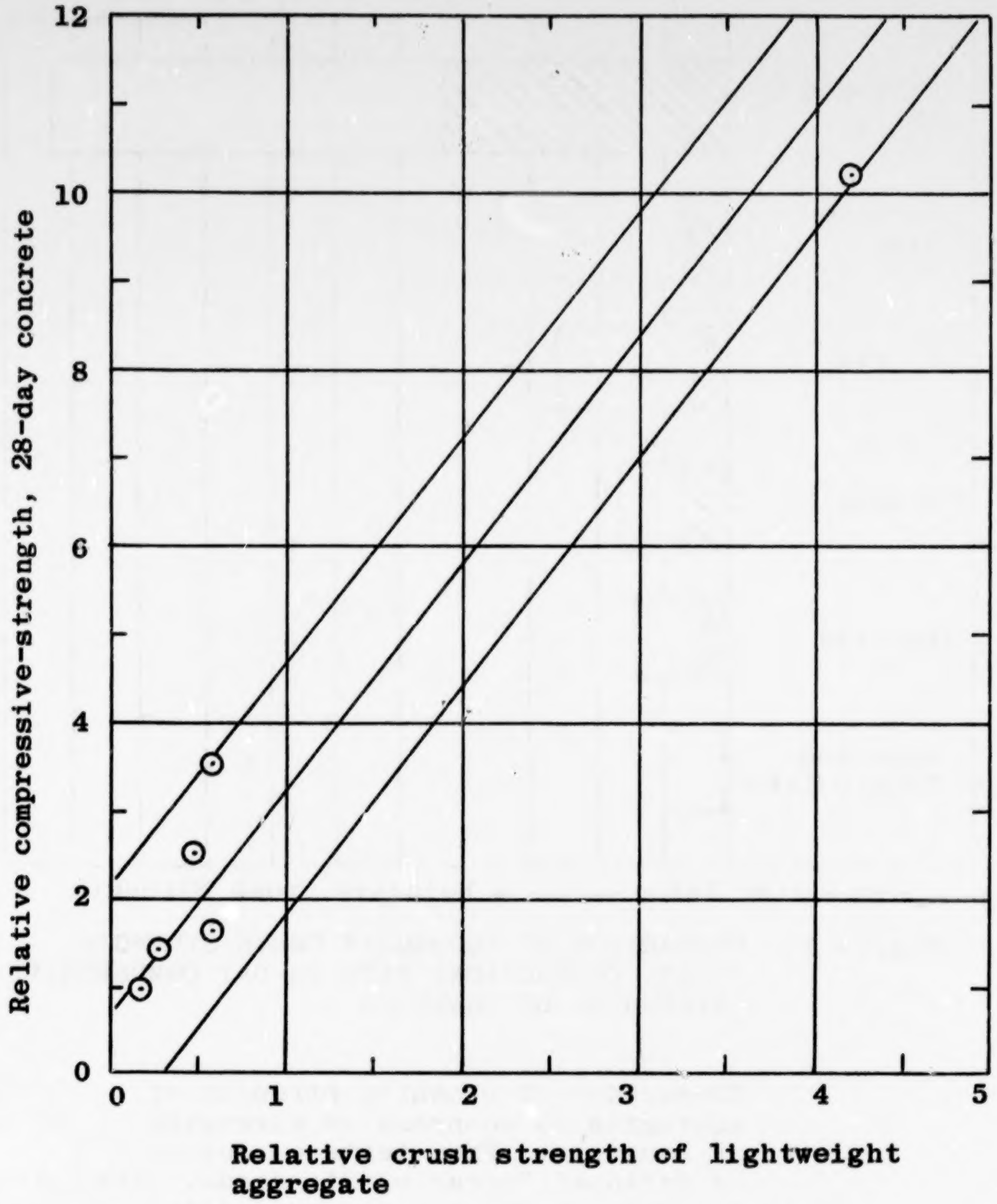


Figure 2. EFFECT OF AGGREGATE CRUSH STRENGTH ON COMPRESSIVE STRENGTH OF CONCRETE (CROSSOLOT OF FIGURE 1)

1 **Accession Number**

2 **Subject Field & Group**

SELECTED WATER RESOURCES ABSTRACTS
INPUT TRANSACTION FORM

5 **Organization**

International Minerals & Chemical Corporation
Skokie, Illinois

6 **Title**

Utilization of Phosphate Slimes

10 **Author(s)**

Vasan, Srini

16 **Project Designation**

EPU #14050

21 **Note**

22 **Citation**

23 **Descriptors (Starred First)**

*Lightweight aggregate, clays, slimes, phosphate mining, slurry pumping, fluid-bed drying, pelletizing, kilning, lightweight concrete, water re-use, land rehabilitation.

25 **Identifiers (Starred First)**

*Lightweight aggregate, from waste phosphate slimes.

27 **Abstract**

Small scale tests were made to assess the feasibility of producing materials economically for the building industry from the clay slimes wastes of the Florida phosphate industry. The objective was to find practical means to utilize these clay materials in order to reduce or eliminate the vast empoundment acreage devoted to their storage and to make the water entrapped therein available for re-use.

These studies showed that it is feasible to produce a pelletized lightweight aggregate and ultimately a lightweight concrete from the slimes. It was estimated that up to 6 - 8 million tons of clay solids can be so used annually with the concurrent release of up to 5 billion gallons of water into the environment. Production of ceramic materials was also explored.

The four major processing steps were investigated batchwise on individual equipment types, and equipment suitable for each was identified. These steps included: pumping clay-slurries of 3 - 30% solids concentration; drying of the slimes in a fluid-bed dryer; pelletizing the dried product; and kilning it to a suitable lightweight aggregate

Abstractor Srini Vasan

Institution International Minerals & Chemical Corporation

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